Final

Environmental Impact Statement

for a

Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

Volume II

Appendixes A through O

U.S. Department of Energy
Office of Civilian Radioactive Waste Management

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ACRONYMS AND ABBREVIATIONS

To ensure a more reader-friendly document, the U.S. Department of Energy (DOE) limited the use of acronyms and abbreviations in this environmental impact statement. In addition, acronyms and abbreviations are defined the first time they are used in each chapter or appendix. The acronyms and abbreviations used in the text of this document are listed below. Acronyms and abbreviations used in tables and figures because of space limitations are listed in footnotes to the tables and figures.

CFR	Code of Federal Regulations
DOE	U.S. Department of Energy (also called *the Department*)
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FR	*Federal Register*
LCF	latent cancer fatality
MTHM	metric tons of heavy metal
NEPA	National Environmental Policy Act, as amended
NRC	U.S. Nuclear Regulatory Commission
NWPA	Nuclear Waste Policy Act, as amended
PM_{10}	particulate matter with an aerodynamic diameter of 10 micrometers or less
$PM_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 micrometers or less
REMI	Regional Economic Models, Inc.
RMEI	reasonably maximally exposed individual
Stat.	United States Statutes
TSPA	Total System Performance Assessment
U.S.C.	United States Code

UNDERSTANDING SCIENTIFIC NOTATION

DOE has used scientific notation in this EIS to express numbers that are so large or so small that they can be difficult to read or write. Scientific notation is based on the use of positive and negative powers of 10. The number written in scientific notation is expressed as the product of a number between 1 and 10 and a positive or negative power of 10. Examples include the following:

Positive Powers of 10	**Negative Powers of 10**
$10^1 = 10 \times 1 = 10$	$10^{-1} = 1/10 = 0.1$
$10^2 = 10 \times 10 = 100$	$10^{-2} = 1/100 = 0.01$
and so on, therefore,	and so on, therefore,
$10^6 = 1,000,000$ (or 1 million)	$10^{-6} = 0.000001$ (or 1 in 1 million)

Probability is expressed as a number between 0 and 1 (0 to 100 percent likelihood of the occurrence of an event). The notation 3×10^{-6} can be read 0.000003, which means that there are three chances in 1,000,000 that the associated result (for example, a fatal cancer) will occur in the period covered by the analysis.

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Appendix A

Inventory and Characteristics of Spent Nuclear Fuel, High-Level Radioactive Waste, and Other Materials

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APPENDIX A. INVENTORY AND CHARACTERISTICS OF SPENT NUCLEAR FUEL, HIGH-LEVEL RADIOACTIVE WASTE, AND OTHER MATERIALS

A.1 Introduction

This appendix describes the inventory and characteristics of the spent nuclear fuel and high-level radioactive waste that the U.S. Department of Energy (DOE) anticipates it would place in a monitored geologic repository at Yucca Mountain. It includes information about other highly radioactive material that DOE could dispose of in the proposed repository. It also provides information on the background and sources of the material, present storage conditions, the final disposal forms, and the amounts and characteristics of the material. The data provided in this appendix are the best available estimates of projected inventories.

The Proposed Action inventory evaluated in this environmental impact statement (EIS) consists of 70,000 metric tons of heavy metal (MTHM), comprised of 63,000 MTHM of commercial spent nuclear fuel and 7,000 MTHM of DOE materials. The DOE materials consist of 2,333 MTHM of spent nuclear fuel and 4,667 MTHM (8,315 canisters) of solidified high-level radioactive waste. The inventory includes surplus weapons-usable plutonium, which would be in the forms of spent mixed-oxide fuel and immobilized plutonium.

The Nuclear Waste Policy Act, as amended (also called the NWPA), prohibits the U.S. Nuclear Regulatory Commission from approving the emplacement of more than 70,000 MTHM in the first repository until a second repository is in operation [Section 114(d)]. However, in addition to the Proposed Action, this EIS evaluates the cumulative impacts for two additional inventories (referred to as Inventory Modules 1 and 2):

- The Module 1 inventory consists of the Proposed Action inventory plus the remainder of the total projected inventory of commercial spent nuclear fuel (for maximum projections, see Section A.2.1.5.1), high-level radioactive waste, and DOE spent nuclear fuel. Emplacement of Inventory Module 1 wastes in the repository would raise the total amount emplaced above 70,000 MTHM. As mentioned above, emplacement of more than 70,000 MTHM of spent nuclear fuel and high-level radioactive waste would require legislative action by Congress unless a second licensed repository was in operation.

- Inventory Module 2 includes the Module 1 inventory plus the inventories of the candidate materials, commercial Greater-Than-Class-C low-level radioactive waste and DOE Special-Performance-Assessment-Required waste. There are several reasons to evaluate the potential for disposing of these candidate materials in a monitored geologic repository in the near future. Because both materials exceed Class C low-level radioactive limits for specific radionuclide concentrations as defined in 10 CFR Part 61, they are generally unsuitable for near-surface disposal. Also, the Nuclear Regulatory Commission specifies in 10 CFR 61.55(a)(2)(iv) the disposal of Greater-Than-Class-C waste in a repository unless the Commission approved disposal elsewhere. Further, during the scoping process for this EIS, several commenters requested that DOE evaluate the disposal of other radioactive waste types that might require isolation in a repository. Disposal of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes at the proposed Yucca Mountain Repository could require a determination by the Nuclear Regulatory Commission that these wastes require permanent isolation. The present 70,000-MTHM limit on waste at the Yucca Mountain Repository could have to be addressed either by legislation or by opening a second licensed repository.

The Yucca Mountain Science and Engineering Report evaluates the 70,000-MTHM Proposed Action inventory as the base case for analysis (DIRS 153849-DOE 2001, all) and considers a repository layout for a best estimate "full inventory" case (DIRS 153849-DOE 2001, p. 2-83), which would accommodate approximately 97,000 MTHM.

A.1.1 INVENTORY DATA SUMMARY

There are six general inventory categories, as follows:

- Commercial spent nuclear fuel
- DOE spent nuclear fuel
- High-level radioactive waste
- Surplus weapons-usable plutonium
- Commercial Greater-Than-Class-C waste
- DOE Special-Performance-Assessment-Required waste

This section summarizes the detailed inventory data in Section A.2. The data provide a basis for the impact analysis in this EIS. Data are provided for the candidate materials included in the initial 70,000 MTHM for the Proposed Action and other inventory that is not currently proposed but might be considered for repository disposal in the foreseeable future.

This summary provides general descriptive and historic information about each waste type, including the following:

- Primary purpose and use of the data
- General comparison of the data between waste types
- Potential for change in inventory data

Table A-1 lists the inventory data that DOE used in the EIS analyses and their descriptions throughout the document.

A.1.1.1 Sources

Figure A-1 shows the locations of generators or sources of spent nuclear fuel and high-level radioactive waste. Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation. The Proposed Action includes the disposal of 63,000 MTHM of commercial spent nuclear fuel in the repository. More than 99 percent of the commercial spent nuclear fuel would come from commercial nuclear reactor sites in 33 states (DIRS 104382-DOE 1995, all). In addition, DOE manages an inventory of spent nuclear fuel. The Proposed Action includes 2,333 MTHM of spent nuclear fuel from four DOE locations: the Savannah River Site in South Carolina, the Hanford Site in Washington, the Idaho National Engineering and Environmental Laboratory, and Fort St. Vrain in Colorado.

High-level radioactive waste is the highly radioactive material resulting from the reprocessing or treatment of spent nuclear fuel. The Proposed Action includes disposing of 4,667 MTHM of high-level radioactive waste in the repository. High-level radioactive waste is stored at the Savannah River Site, the Hanford Site, the Idaho National Engineering and Environmental Laboratory, and the West Valley Demonstration Project in New York.

The President has declared an amount of plutonium to be surplus to national security needs (DIRS 118979-DOE 1999, p. 1-3). This surplus weapons-usable plutonium includes purified plutonium, nuclear weapons components, and plutonium residues. This inventory is included in the Proposed Action, and the Department would dispose of it as either spent mixed oxide fuel from a commercial nuclear reactor

Table A-1. Use of Appendix A radioactivity inventory data in EIS chapters and appendixes (page 1 of 2).

Item[a]	Appendix A	EIS section
Number of commercial nuclear sites	Table A-3	1.1, 2.2, 2.2.2, 2.4.1, 6.1, Ch. 7 introduction, 7.2, 7.2.1, 7.3, J.1.3.1.1
Number of DOE sites	A.1.1.1	1.1, 2.2, 2.2.2, 2.4.1, 6.1, Ch. 7 introduction, 7.2, 7.2.1, 7.3
Mapped location of sites	Figure A-1	Figure 1-1, several Chapter 6, 7, App. J and K figures
Commercial SNF material	A.2.1.5.3	1.2.2.1
Commercial SNF dimensions	Table A-18	1.2.1 and Figure 1-2
Commercial SNF cladding material	A.2.1.5.3	1.2.2.1, K.2.1.4.1
Percentage of commercial SNF with stainless-steel cladding	A.2.1.5.3	1.2.2.1, 5.5.1, K.2.1.4.1
MOX SNF part of commercial SNF Proposed Action	A.2.4.5.1.1	1.2.2.1, 1.2.4
Number of sites with existing or planned ISFSIs	Table A-4	1.2.1
Amount of commercial SNF projected for each site	Tables A-7 and A-8	6.1.1, K.2.1.6
DOE SNF storage locations	Table A-20	1.2.2.2, K.2.1.6
HLW generators	A.2.3.2	1.2.3
HLW vitrification status	A.2.3.3	1.2.3
Weapons-usable Pu declared surplus	A.2.4.1	1.2.4
Two forms: MOX and immobilized Pu	A.2.4.1	1.2.4
Proposed Action inventory	A.1	1.2.2.1, 2.1, 5.1, 8.1.2.1, K.2.2
Total projected inventory commercial SNF	Figure A-2	7.2, 7.3, 8.1.2.1
Total projected inventory DOE SNF	Figure A-2	7.2, 7.3, 8.1.2.1, K.2.2
Total projected inventory HLW	Figure A-2	7.2, 7.3, 8.1.2.1, K.2.2
Total projected GTCC waste	Table A-54	7.3, 8.1.2.1, I.3.1.3
Total projected SPAR waste	Table A-59	7.3, 8.1.2.1, I.3.1.3
Kr-85 (gas) is contained in fuel gap of commercial SNF	A.2.1.5.2	4.1.2.3.2, H.2.1.4.1.2
Radionuclide inventory for commercial SNF	Tables A-9, A-10, and A-11	4.1.8.1, H.2.1.4, Table H-4, J.1.4.2.1, K.2.2
Cs-137, actinide, and total curies contained in a rail shipping cask for commercial SNF, HLW, DOE SNF, and naval fuel	Derived from Tables A-10, A-21, and A-28	Table J-12, Table J-15
Radiological inventory of GTCC and SPAR waste much less than commercial SNF or HLW	Derived from Tables A-9, A-21, A-28, A-57, and Section A.2.6.4	8.2.7, 8.2.8, 8.4.1.1, F.3
Average radionuclide inventory per package for SPAR and GTCC waste	Derived from Table A-57 and Section A.2.6.4	8.3.1.1, Table I-7
C-14 (gas) is contained in fuel gap of commercial SNF	Tables A-9, A-10, and A-11	5.5, 8.3.1.1, H.2.1.4.1.2, I.3.3, I.7
PWR burnup, initial enrichment, and average cooling time	A.2.1.5	G.2.3.2, J.1.4.2.1
BWR burnup, initial enrichment, and average cooling time	A.2.1.5	G.2.3.2
DOE SNF radionuclide inventory	Table A-21	

Table A-1. Use of Appendix A radioactivity inventory data in EIS chapters and appendixes (page 2 of 2).

Item[a]	Appendix A	EIS section
Assumed packaging method for GTCC and SPAR	A.2.5.4, A.2.6.4	I.3.1.3
Chemical makeup of waste inventory	Tables A-15, A-16, A-22, A-32, A-33, A-34, A-35, A-36, and A-37	Table I-8
MTHM per assembly for PWR and BWR	Table A-17	J.1.3.1.1
Most HLW stored in underground vaults	A.2.3.3	K.2.1.5.3

a. Abbreviations: SNF = spent nuclear fuel; MOX = mixed oxide; ISFSI = independent spent fuel storage installation; HLW = high-level radioactive waste; Pu = plutonium; GTCC = Greater-Than-Class-C; SPAR = Special-Performance-Assessment-Required; MTHM = metric tons of heavy metal; Kr = krypton; Cs = cesium; PWR = pressurized-water reactor; BWR = boiling-water reactor.

(that is, commercial spent nuclear fuel) or immobilized plutonium in a high-level radioactive waste canister (that is, as high-level radioactive waste), or a combination of these two inventory categories (DIRS 118979-DOE 1999, p. 1-3). Spent mixed-oxide fuel would come from one or more of the existing commercial reactor sites. DOE has selected the Savannah River site in South Carolina as the location for the immobilized plutonium disposition facilities.

For purposes of analysis, this EIS assumes that the high-level radioactive waste canisters, which would contain immobilized plutonium and borosilicate glass, would come from the Savannah River Site.

Greater-Than-Class-C waste is waste with concentrations of certain radionuclides that exceed the Class C limits stated in 10 CFR Part 61, thereby making it unsuitable for near-surface disposal. Greater-Than-Class-C waste is generated by a number of sources including commercial nuclear utilities, sealed radioactive sources, and wastes from "other generators." These other generators include carbon-14 users, industrial research and development applications, fuel fabricators, university reactors, and others. These wastes are currently stored at the commercial and DOE sites and exist in most states. They are included in Inventory Module 2 of the EIS but are not part of the Proposed Action.

Special-Performance-Assessment-Required wastes are also Greater-Than-Class-C wastes managed by DOE and are stored primarily at the Hanford Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Oak Ridge National Laboratory in Tennessee. These wastes are included in Inventory Module 2 of the EIS but are not part of the Proposed Action.

A.1.1.2 Present Storage and Generation Status

Commercial spent nuclear fuel is stored at reactor sites in either a spent fuel pool or in a dry storage configuration generally referred to as an independent spent fuel storage installation. Through 1999, approximately 40,000 MTHM of commercial spent nuclear fuel has been discharged from reactors (DIRS 153849-DOE 2001, p. 1-10). DOE spent nuclear fuel is also stored either underwater in basins or in a dry storage configuration.

As discussed in the next section, DOE would receive high-level radioactive waste at the repository in a solidified form in stainless-steel canisters. Until shipment to the repository, the canisters would be stored at the commercial and DOE sites. With the exception of the West Valley Demonstration Project, filled canisters are stored in below-grade facilities. The West Valley canisters would be stored in an above-ground shielded facility.

Legend

★ Commercial sites

Note: The EIS analysis considered three commercial site pairs — Salem and Hope Creek, Nine Mile Point and FitzPatrick, and Dresden and Morris — to be single sites due to their proximity to each other.

◉ DOE sites

Note: The EIS analysis included the high-level radioactive waste at West Valley. The State of New York owns the high-level radioactive waste and the site. Under the West Valley Demonstration Project Act, DOE is responsible for solidifying and transporting the high-level radioactive waste to a repository.

▲ Yucca Mountain

Symbols do not reflect precise locations.

Source: Modified from DIRS 101779-DOE (1998, Overview, p. 5).

Figure A-1. Locations of commercial and DOE sites and Yucca Mountain.

A.1.1.3 Final Waste Form

Other than drying or potential repackaging, treating is not necessary for commercial spent nuclear fuel. Therefore, the final form would be spent nuclear fuel either as bare intact assemblies or in sealed canisters. Bare intact fuel assemblies are those with structural and cladding integrity such that they can be handled and shipped to the repository in an approved shipping container for repackaging in a waste package in the Waste Handling Building. Other assemblies would be shipped to the repository in canisters that were either intended or not intended for disposal. Canisters not intended for disposal would be opened and their contents repackaged in waste packages in the Waste Handling Building.

For most of the DOE spent nuclear fuel categories, the fuel would be shipped in disposable canisters (canisters that can be shipped and are suitable for direct insertion into waste packages without being opened) in casks licensed by the Nuclear Regulatory Commission. Uranium oxide fuels with intact zirconium alloy cladding are similar to commercial spent nuclear fuel and could be shipped either in DOE standard canisters or as bare intact assemblies. Uranium metal fuels from Hanford and aluminum-based fuels from the Savannah River Site could require additional treatment or conditioning before shipment to the repository. If treatment was required, these fuels would be packaged in DOE disposable canisters. Category 14 sodium-bonded fuels are also expected to require treatment before disposal.

High-level radioactive waste shipped to the repository would be in stainless-steel canisters. The waste would have undergone a solidification process that yielded a leach-resistant material, typically a glass form called borosilicate glass. In this process, the high-level radioactive waste is mixed with glass-forming materials, heated and converted to a durable glass waste form, and poured into stainless-steel canisters (DIRS 104406-Picha 1997, Attachment 4, p. 2). Ceramic and metal waste matrices would be sent to the repository from Argonne National Laboratory-West in Idaho. The ceramic and metal matrices would be different solidified mixtures that also would be in stainless-steel canisters. These wastes would be the result of the electrometallurgical treatment of sodium bonded fuels.

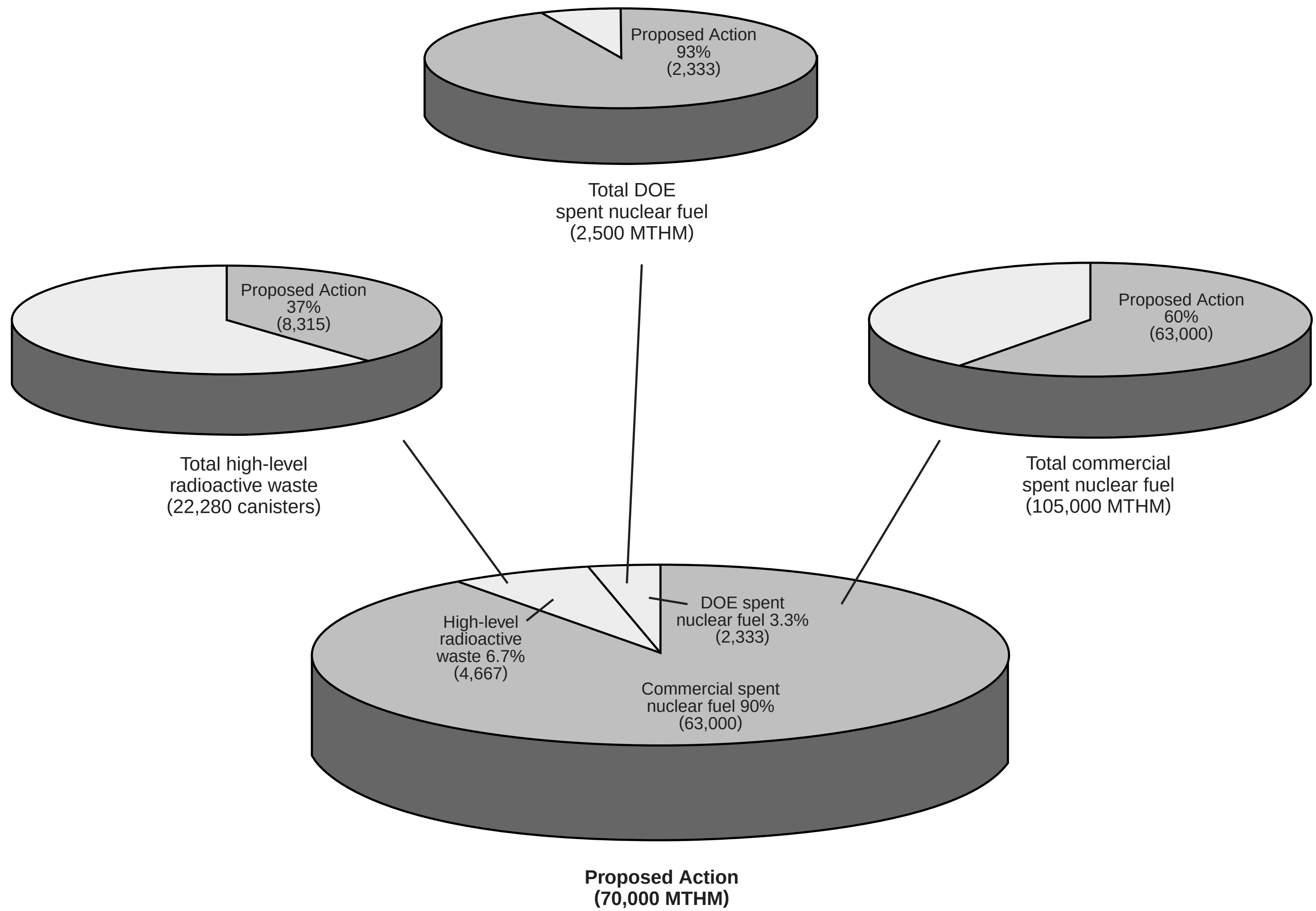
As briefly described in Section A.1.1.1, the surplus weapon-usable plutonium could be sent to the repository in two different waste forms—spent mixed-oxide fuel assemblies or an immobilized plutonium ceramic form in a high-level radioactive waste canister and surrounded by high-level radioactive waste. The spent mixed-oxide fuel assemblies would be very similar to conventional low-enriched uranium assemblies and DOE would treat them as such. The immobilized plutonium would be placed in small cans, inserted in the high-level radioactive waste canisters, and covered with molten borosilicate glass (can-in-canister technique). The canisters containing immobilized plutonium and high-level radioactive waste would be externally identical to the normal high-level radioactive waste canisters.

A.1.1.4 Waste Characteristics

A.1.1.4.1 *Mass and Volume*

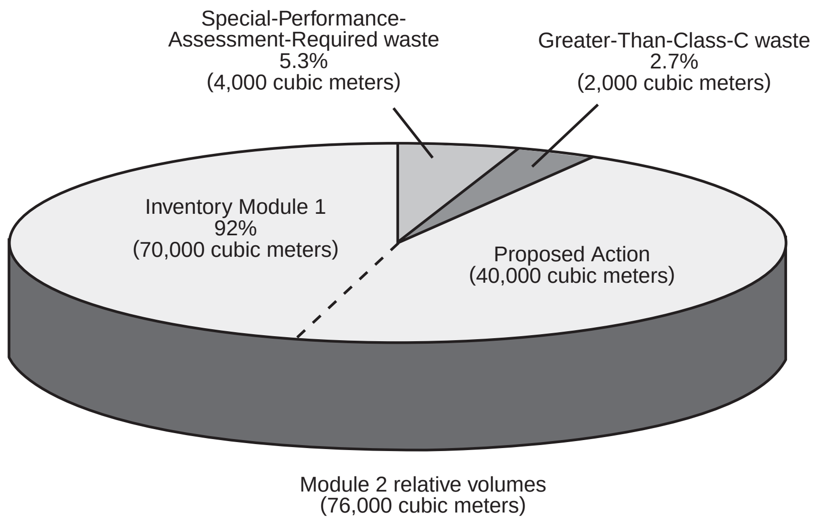
As discussed in Section A.1, the Proposed Action includes 70,000 MTHM in the forms of commercial spent nuclear fuel, DOE spent nuclear fuel, high-level radioactive waste, and surplus weapons-usable plutonium. Figure A-2 shows percentages of MTHM included in the Proposed Action and the relative amounts of the totals of the individual waste types included in the Proposed Action. As stated above, the remaining portion of the wastes is included in Inventory Module 1. Because Greater-Than-Class-C and Special-Performance-Assessment-Required wastes are measured in terms of volume, Figure A-3 shows the relative volume of the wastes in Inventory Module 2 compared to the inventory in Module 1.

The No-Action Alternative (see Chapter 7 and Appendix K) used this information to estimate the mass and volume of the spent nuclear fuel and high-level radioactive waste at commercial and DOE sites in five regions of the contiguous United States.



Sources: DIRS 103493-DOE (1997, page 32); DIRS 148240-Dirkmaat (1998, all); DIRS 104406-Picha (1997, Attachment 1, page 1); DIRS 104407-Picha (1998, Attachment 1).

Figure A-2. Proposed Action spent nuclear fuel and high-level radioactive waste inventory.



To convert cubic meters to cubic yards, multiply by 1.3079.

Sources: DIRS 148240-Dirkmaat (1998, all); DIRS 101798-DOE (1994, all); DIRS 101815-DOE (1997, p. 1-8); DIRS 104394-Heath (1998, Appendixes B and C); DIRS 104406-Picha (1997, Attachment 1, p. 1); DIRS 104407-Picha (1998, Attachment 1); DIRS 104411-Picha (1998, all).

Figure A-3. Inventory Module 2 volume.

The mass and volume data for commercial spent nuclear fuel are based on annual tracking of current inventories and projections of future generations. Because increases in spent nuclear fuel inventories due to plant life extensions have been factored into the Module 1 and 2 inventories, DOE anticipates few changes in the overall mass and volume projections for this waste type. The data projections for DOE spent nuclear fuel are fairly stable because most of the projected inventory already exists, as opposed to having a large amount projected for future generation. Mass and volume data for high-level radioactive waste estimates are not as reliable. Most high-level radioactive waste currently exists as a form other than solidified borosilicate glass. The solidification processes at the Savannah River Site and West Valley Demonstration Project began in the mid-1990s; therefore, their resulting masses and volumes are known. However, the processes at the Idaho National Engineering and Environmental Laboratory and the Hanford Site have not started. Therefore, there is some uncertainty about the mass and volume that would result from those processing operations. For this analysis, DOE assumed that the high-level radioactive waste from the Hanford Site and the Idaho National Engineering and Environmental Laboratory would represent approximately 63 and 6 percent of the total high-level radioactive waste inventory, respectively, in terms of the number of canisters.

A.1.1.4.2 *Radionuclide Inventories*

The primary purpose of presenting these data is to quantify the radionuclide inventory expected in the projected waste types. These data were used for accident scenario analyses associated with transportation, handling, and repository operations.

In a comparison of the relative amounts of radioactivity in a particular waste type, radionuclides of concern depend on the analysis being performed. For example, cesium-137 is the primary radionuclide of concern when reviewing preclosure impacts and shielding requirements. For postclosure impacts, the repository performance assessment identified technetium-99 and neptunium-237 as the nuclides that provide the greatest impacts. Plutonium-238 and -239 are shown in Chapter 7 to contribute the most to doses for the No-Action Alternative. Table A-2 presents the inventory of each of these radionuclides included in the Proposed Action. Figure A-4 shows that at least 92 percent of the total inventory of each of these radionuclides is in commercial spent nuclear fuel.

Table A-2. Selected radionuclide inventory for the Proposed Action (curies).[a]

Radionuclide[b]	Commercial spent nuclear fuel	DOE spent nuclear fuel	High-level radioactive waste	Surplus plutonium	Totals
Cesium-137	4.5×10^9	1.7×10^8	1.7×10^8	NA[c]	4.8×10^9
Technetium-99	9.5×10^5	2.9×10^4	2.1×10^4	NA	1.0×10^6
Neptunium-237	3.0×10^4	4.8×10^2	4.5×10^2	NA	3.1×10^4
Plutonium-238	2.4×10^8	5.6×10^6	3.0×10^6	7.6×10^4	2.5×10^8
Plutonium-239	2.4×10^7	3.8×10^5	4.4×10^4	1.0×10^6	2.5×10^7

a. Source: Compiled from Tables A-11, A-21, A-28, A-29, A-30, A-31, A-50, and A-51.
b. Half-lives are listed in Table A-11.
c. NA = not applicable.

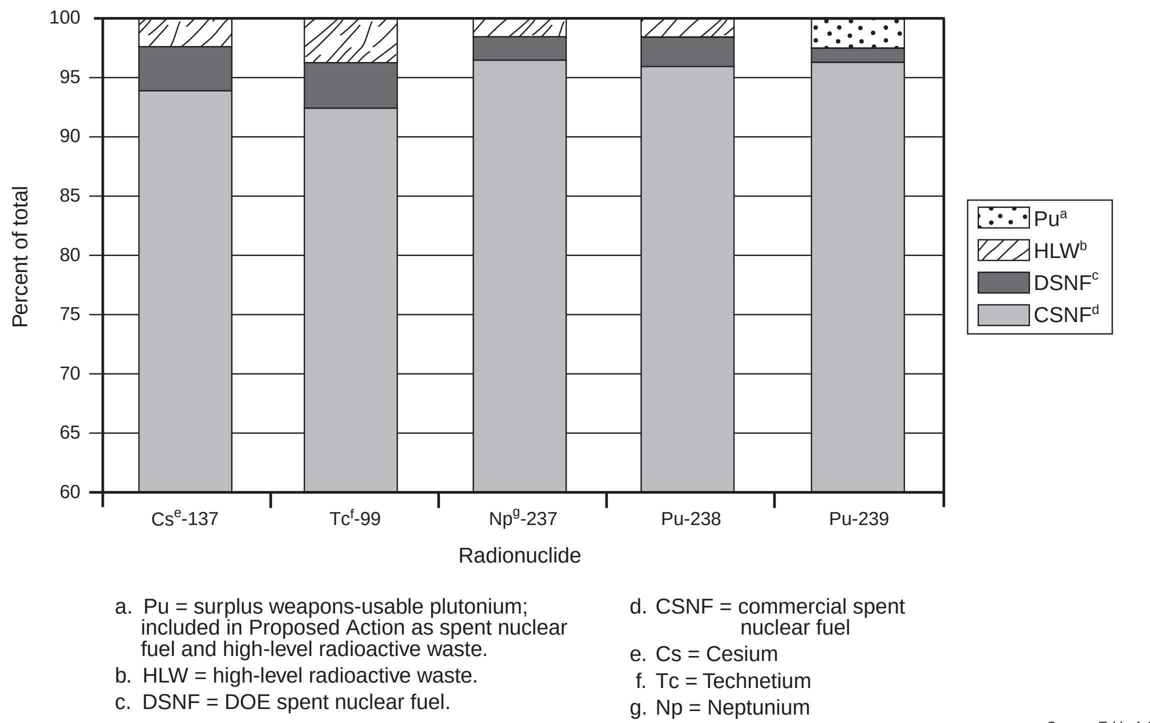


Figure A-4. Proposed Action radionuclide distribution by material type.

A.1.1.4.3 *Chemical Composition*

The appendix presents data for the chemical composition of the primary waste types. For commercial spent nuclear fuel, the elemental composition of typical pressurized-water and boiling-water reactor fuel is provided on a per-assembly basis. Data are also provided on the number of stainless-steel clad assemblies in the current inventory.

For DOE spent nuclear fuel and high-level radioactive waste, this appendix contains tables that describe the composition of the total inventory of the spent nuclear fuel (by representative category) or high-level radioactive waste (by site).

A.1.1.4.4 *Thermal Output*

Thermal generation data associated with each material type are provided in this appendix.

The data presented in the thermal output sections of this appendix for each waste type are presented as watts per assembly or MTHM for commercial spent nuclear fuel, and watts per canister for DOE spent nuclear fuel or high-level radioactive waste. Figure A-5 normalizes these data into a common, watts-per-waste-package comparison. The following waste packages are compared: one containing 21 average pressurized-water reactor assemblies, one containing 44 average boiling-water reactor assemblies, a codisposal waste package containing five high-level radioactive waste canisters and one DOE spent nuclear fuel canister, and a waste package containing one dual-purpose canister of naval spent nuclear fuel (also a DOE spent fuel).

Figure A-5 uses conservative assumptions to illustrate the bounding nature of the thermal data for commercial spent nuclear fuel. The commercial spent nuclear fuel data represent average assemblies that are assumed to have cooled for about 25 years. The naval spent nuclear fuel data are a best estimate of the thermal generation of a canister of naval spent nuclear fuel at a minimum cooling time of 5 years. The thermal data selected for the high-level radioactive waste are conservatively represented by the canisters from the Savannah River Site and are combined with the highest values of thermal output from all projected DOE spent nuclear fuel categories. As noted in Chapter 2, blending of hot and cold commercial spent nuclear fuel could be employed to meet waste package thermal load limits.

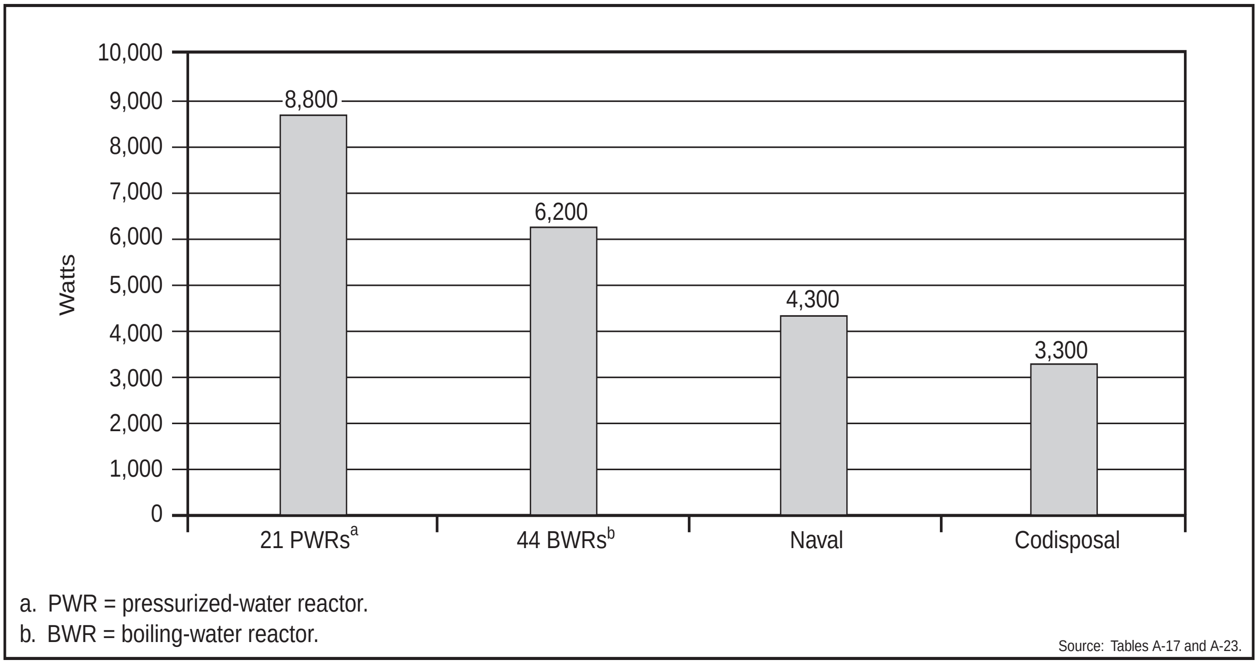


Figure A-5. Thermal generation (watts per waste package).

A.1.1.4.5 *Canister Data*

Commercial spent nuclear fuel, which would be shipped in canisters not suitable for disposal, would be removed from the canister and placed in a waste package. Typically, DOE spent nuclear fuel and high-level radioactive waste would be sent to the repository in disposable canisters. The design specifications for DOE spent nuclear fuel canisters are in DIRS 137713-DOE (1998, all). These canisters are generally of two diameters—nominally 46 and 61 centimeters (18 and 24 inches). They also would be designed for two different lengths, nominally 3 and 4.5 meters (10 and 15 feet), to enable codisposal with high-level radioactive waste canisters. Certain DOE spent nuclear fuel categories require specific disposal canister designs. Naval fuels would be sent to the repository in disposable canisters, which are described in DIRS 125735-Guida (1997, all) and DIRS 101941-USN (1996, pp. 3-1 to 3-11). N-Reactor fuels from the

Hanford Site would be sent to the repository in multicanister overpacks 64 centimeters (25.3 inches) in diameter, 420 centimeters (65 inches) long, which are described in DIRS 148489-DE&S Hanford (1997, all).

High-level radioactive waste would be sent to the repository in stainless-steel canisters, nominally 61 centimeters (24 inches) in diameter and either 3 or 4.5 meters (10 or 15 feet) in length, depending on the DOE site. The canister design specifications are contained in DIRS 101854-Marra, Harbour, and Plodinec (1995, all) and DIRS 103500-WVNS (n.d., WQR-2.2) for the operating vitrification processes at Savannah River Site and West Valley Demonstration Project, respectively. The other sites would use canister designs similar to those currently in use (DIRS 104406-Picha 1997, all).

These data were for analysis of the No-Action Alternative (see Chapter 7 and Appendix K) to determine the time required to breach the canisters after they are exposed to weather elements.

A.2 Materials

This section describes the characteristics of the materials DOE has considered for disposal in the proposed Yucca Mountain Repository. All candidate materials would have to meet approved acceptance criteria.

A.2.1 COMMERCIAL SPENT NUCLEAR FUEL

A.2.1.1 Background

Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation. Spent nuclear fuel from light-water reactors (pressurized-water and boiling-water reactors) would be the primary source of radioactivity and thermal load in the proposed monitored geologic repository. Spent nuclear fuels from civilian research reactors (General Atomics, Aerotest, etc.) account for less than 0.001 percent of the projected total in the Proposed Action (DIRS 104382-DOE 1995, all). The fuels addressed in this section are those discharged from commercial light-water reactors.

Section A.2.2 discusses the spent nuclear fuel from the Fort St. Vrain reactor in Colorado as part of DOE spent nuclear fuels, as are the fuels from Shippingport, Three Mile Island-2, and other fuels from commercial facilities that DOE has taken title to and is managing at its facilities.

A.2.1.2 Sources

The sources of commercial spent nuclear fuel are the commercial nuclear powerplants throughout the country. Table A-3 lists the individual reactors, reactor type, state, and actual or projected years of operation. The operating periods reflect six plants that have recently been granted extensions to their operating licenses. As noted in the table, additional extensions could be forthcoming, which could extend some of the operating periods. The operation period is also subject to change if a utility shuts down early. For conservatism, the estimated inventory of commercial spent nuclear fuel in Modules 1 and 2 was derived from the Energy Information Administration’s “high case” projections. The high case assumes that all currently operating nuclear powerplants would renew their operating licenses for an additional 10 years.

A.2.1.3 Present Status

Nuclear power reactors store spent nuclear fuel in spent fuel pools under U.S. Nuclear Regulatory Commission licenses, and they can combine that option with above-grade dry storage in an independent

Table A-3. Commercial nuclear power reactors in the United States and their projected years of operation.[a]

Unit name	Reactor type[b]	State	Operations period[c]	Unit name	Reactor type[b]	State	Operations period[c]
Arkansas Nuclear One 1[d]	PWR	AR	1974-2034	Millstone 2	PWR	CT	1975-2015
Arkansas Nuclear One 2	PWR	AR	1978-2018	Millstone 3	PWR	CT	1986-2025
Beaver Valley 1	PWR	PA	1976-2016	Monticello	BWR	MN	1971-2010
Beaver Valley 2	PWR	PA	1978-2018	Nine Mile Point 1	BWR	NY	1969-2009
Big Rock Point	BWR	MI	1963-1997	Nine Mile Point 2	BWR	NY	1987-2026
Braidwood 1	PWR	IL	1987-2026	North Anna 1	PWR	VA	1978-2018
Braidwood 2	PWR	IL	1988-2027	North Anna 2	PWR	VA	1980-2020
Browns Ferry 1	BWR	AL	1973-2013	Oconee 1[d]	PWR	SC	1973-2033
Browns Ferry 2	BWR	AL	1974-2014	Oconee 2[d]	PWR	SC	1973-2033
Browns Ferry 3	BWR	AL	1976-2016	Oconee 3[d]	PWR	SC	1974-2034
Brunswick 1	BWR	NC	1976-2016	Oyster Creek	BWR	NJ	1969-2009
Brunswick 2	BWR	NC	1974-2014	Palisades	PWR	MI	1972-2007
Byron 1	PWR	IL	1985-2024	Palo Verde 1	PWR	AZ	1985-2024
Byron 2	PWR	IL	1987-2026	Palo Verde 2	PWR	AZ	1986-2025
Callaway	PWR	MO	1984-2024	Palo Verde 3	PWR	AZ	1987-2027
Calvert Cliffs 1[d]	PWR	MD	1974-2034	Peach Bottom 2	BWR	PA	1973-2013
Calvert Cliffs 2[d]	PWR	MD	1976-2036	Peach Bottom 3	BWR	PA	1974-2014
Catawba 1	PWR	SC	1985-2024	Perry 1	BWR	OH	1986-2026
Catawba 2	PWR	SC	1986-2026	Pilgrim 1	BWR	MA	1972-2012
Clinton	BWR	IL	1987-2026	Point Beach 1	PWR	WI	1970-2010
Comanche Peak 1	PWR	TX	1990-2030	Point Beach 2	PWR	WI	1973-2013
Comanche Peak 2	PWR	TX	1993-2033	Prairie Island 1	PWR	MN	1974-2013
Cooper Station	BWR	NE	1974-2014	Prairie Island 2	PWR	MN	1974-2014
Crystal River 3	PWR	FL	1977-2016	Quad Cities 1	BWR	IL	1972-2012
D. C. Cook 1	PWR	MI	1974-2014	Quad Cities 2	BWR	IL	1972-2012
D. C. Cook 2	PWR	MI	1977-2017	Rancho Seco	PWR	CA	1974-1989
Davis-Besse	PWR	OH	1977-2017	River Bend 1	BWR	LA	1985-2025
Diablo Canyon 1	PWR	CA	1984-2021	Salem 1	PWR	NJ	1976-2016
Diablo Canyon 2	PWR	CA	1985-2025	Salem 2	PWR	NJ	1981-2020
Dresden 1	BWR	IL	1959-1978	San Onofre 1	PWR	CA	1967-1992
Dresden 2	BWR	IL	1969-2006	San Onofre 2	PWR	CA	1982-2013
Dresden 3	BWR	IL	1971-2011	San Onofre 3	PWR	CA	1983-2013
Duane Arnold 1	BWR	IA	1974-2014	Seabrook 1	PWR	NH	1990-2026
Edwin I. Hatch 1	BWR	GA	1974-2014	Sequoyah 1	PWR	TN	1980-2020
Edwin I. Hatch 2	BWR	GA	1978-2018	Sequoyah 2	PWR	TN	1981-2021
Fermi 2	BWR	MI	1985-2025	Shearon Harris	PWR	NC	1987-2026
Fort Calhoun 1	PWR	NE	1973-2013	South Texas Project 1	PWR	TX	1988-2016
Ginna	PWR	NY	1969-2009	South Texas Project 2	PWR	TX	1989-2023
Grand Gulf 1	BWR	MS	1984-2022	St. Lucie 1	PWR	FL	1976-2016
Haddam Neck	PWR	CT	1968-1996	St. Lucie 2	PWR	FL	1983-2023
Hope Creek	BWR	NJ	1986-2026	Summer 1	PWR	SC	1982-2022
Humboldt Bay	BWR	CA	1962-1976	Surry 1	PWR	VA	1972-2012
H.B. Robinson 2	PWR	SC	1970-2010	Surry 2	PWR	VA	1973-2013
Indian Point 1	PWR	NY	1962-1974	Susquehanna 1	BWR	PA	1982-2022
Indian Point 2	PWR	NY	1973-2013	Susquehanna 2	BWR	PA	1984-2024
Indian Point 3	PWR	NY	1976-2015	Three Mile Island 1	PWR	PA	1974-2014
James A. FitzPatrick/ Nine Mile Point	BWR	NY	1974-2014	Trojan	PWR	OR	1975-1992
				Turkey Point 3	PWR	FL	1972-2012
Joseph M. Farley 1	PWR	AL	1977-2017	Turkey Point 4	PWR	FL	1973-2013
Joseph M. Farley 2	PWR	AL	1981-2021	Vermont Yankee	BWR	VT	1973-2012
Kewaunee	PWR	WI	1973-2013	Vogtle 1	PWR	GA	1987-2027
LaCrosse	BWR	WI	1967-1987	Vogtle 2	PWR	GA	1989-2029
LaSalle 1	BWR	IL	1970-2022	Columbia Generating Station	BWR	WA	1984-2023
LaSalle 2	BWR	IL	1970-2023				
Limerick 1	BWR	PA	1985-2024	Waterford 3	PWR	LA	1985-2024
Limerick 2	BWR	PA	1989-2029	Watts Bar 1	PWR	TN	1996-2035
Maine Yankee	PWR	ME	1972-1996	Wolf Creek	PWR	KS	1985-2025
McGuire 1	PWR	NC	1981-2021	Yankee-Rowe	PWR	MA	1963-1991
McGuire 2	PWR	NC	1983-2023	Zion 1	PWR	IL	1973-1997
Millstone 1	BWR	CT	1970-2010	Zion 2	PWR	IL	1974-1996

a. Source: DIRS 103493-DOE (1997, Appendix C).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. As defined by current shutdown or full operation through license period (as of 1997), except as noted in Footnote d.
d. These plants have recently been granted 20-year operating license extensions. Several additional plants have applied for operating license extensions, and others could do so in the future.

spent fuel storage installation. When a reactor is refueled, spent fuel is transferred to the spent fuel pool, where it typically remains until the available pool capacity is reached. When in-pool storage capacity has been fully used, utilities have turned to dry cask storage in an independent spent fuel storage installation to expand their onsite spent fuel storage capacities. In 1990, the Nuclear Regulatory Commission amended its regulations to authorize licensees to store spent nuclear fuel at reactor sites in approved storage casks (DIRS 101913-Raddatz and Waters 1996, all).

Commercial nuclear utilities currently use three Nuclear Regulatory Commission-approved general dry storage system design types—metal storage casks and metal canisters housed in either concrete casks or concrete vaults—for use in licensed independent spent fuel storage installations. Raddatz and Waters (DIRS 101913-1996, all) contains detailed information on models currently approved by the Commission. Table A-4 lists the numbers of existing and planned at-reactor independent spent fuel storage installations in the United States as of 2001.

Table A-4. Sites with existing or planned independent spent fuel storage installations.[a]

Installations	Number
Existing	18
Planned	15

a. Sources: DIRS 155604-Delligatti (2001, all).

A.2.1.4 Final Spent Nuclear Fuel Form

The final form of commercial spent nuclear fuel to be disposed of in the proposed repository would be the spent reactor fuel assemblies. The repository would receive bare spent nuclear fuel assemblies, spent nuclear fuel packaged in canisters not intended for disposal, and spent nuclear fuel packaged in canisters intended for disposal.

A.2.1.5 Spent Nuclear Fuel Characteristics

There are 22 classes of nuclear fuel assemblies, with 127 individual fuel types in those classes. Seventeen of the classes are for pressurized-water reactor fuels and 5 are for boiling-water reactors (DIRS 102588-DOE 1992, Appendix 2A). For this EIS, the assemblies chosen for analysis represent an assembly type being used in the more recently built reactors. This results in physical characteristics that provide a realistic estimate for EIS analyses. Specifically chosen to represent the fuel types were the Westinghouse 17 × 17 LOPAR fuel assembly for the pressurized-water reactor and the General Electric BWR/4-6, 8 × 8 fuel assembly for the boiling-water reactor. Table A-5 lists the fissile content and performance parameters selected to define the radiological characteristics of these fuel assemblies. These parameters represent the average values for pressurized-water reactor and boiling-water reactor fuel to be received at the proposed repository.

Table A-5. Average spent nuclear fuel parameters.[a]

Fuel type[b]	Burnup (MWd/MTHM)[c]	Initial enrichment (percent of U-235 by weight)	Age (years)
Average PWR	41,200	3.75	23
Average BWR	33,600	3.03	23

a. Source: DIRS 153849-DOE (2001, p. 3-13).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. MWd/MTHM = megawatt-days per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.

In the Draft EIS, Appendix A, DOE used fuel characteristics similar to those in Table A-5 to estimate consequences from accidents during transportation and repository operations. Since the publication of the Draft EIS, there has been concern that the radionuclide inventories of these average fuel assemblies could underestimate the potential dose consequences of an accidental release. In particular, using the average age of fuel likely to be sent to the repository does not fully take into account the effects of exponential radioactive decay and dose potential from accidental releases as the fuel aged.

As a result of these considerations, DOE undertook an effort to evaluate characteristics of commercial pressurized-water and boiling-water reactor spent nuclear fuel assemblies that span the entire range and distribution of the assemblies that would be shipped to the repository (DIRS 156919-Ikenberry 2001, all). The object of the effort was to characterize pressurized-water and boiling-water reactor assemblies that would represent a median hazard over the entire spectrum of commercial spent nuclear fuel. The result of this effort is in Table A-6, which lists the representative fuel used for accident analyses in this Final EIS. The effort included consideration of both mixed oxide (see Section A.2.4.5.1) as well as the bounding fuel types (highest burnup with lowest cooling time).

Table A-6. Representative commercial spent nuclear fuel characteristics for accident analyses.[a]

Fuel type[b]	Burnup (MWd/MTHM)[c]	Initial enrichment (percent of U-235 by weight)	Age (years)
Representative PWR	50,000	4.5	15
Representative BWR	40,000	3.5	14

a. Source: DIRS 156919-Ikenberry (2001, all).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. MWd/MTHM = megawatt-days per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.

A.2.1.5.1 *Mass and Volume*

As discussed in Section A.1, the Proposed Action includes 63,000 MTHM of commercial spent nuclear fuel. For the No-Action Alternative (continued storage) analysis, Table A-7 lists the distribution of this expected inventory by reactor site. The historic and projected spent nuclear fuel discharge and storage information in Table A-7 is consistent with the annual projections provided by the Energy Information Administration (DIRS 103493-DOE 1997, p. 32). The “1995 Actual” data presented in Table A-7 represents the amount of spent nuclear fuel stored at a particular site regardless of the reactor from which it was discharged. For analysis purposes, the table lists spent nuclear fuel currently stored at the General Electric Morris, Illinois, facility to be at Dresden, because these facilities are located near each other.

For analyses associated with the Proposed Action, the projected spent nuclear fuel from pressurized-water reactors comprises 65 percent of the 63,000 metric tons of heavy metal (DIRS 100265-CRWMS M&O 1997, p. A-2). The balance consists of spent nuclear fuel from boiling-water reactors. Using the nominal volume for the spent nuclear fuel assemblies described in Section A.2.1.5.5, the estimated volume of spent nuclear fuel in the Proposed Action, exclusive of packaging, is 29,000 cubic meters.

Section A.1 also discusses the additional inventory modules evaluated in this EIS. Inventory Modules 1 and 2 both include the maximum expected discharge inventory of commercial spent nuclear fuel. Table A-8 lists historic and projected amounts of spent nuclear fuel discharged from commercial reactors through 2046. The estimated unpackaged volume of spent nuclear fuel for these modules is approximately 47,000 cubic meters. For conservatism, these data were derived from the Energy Information Administration “high case” assumptions. The high case assumes that all currently operating nuclear units would renew their operating licenses for an additional 10 years (DIRS 103493-DOE 1997, p. 32).

A.2.1.5.2 *Amount and Nature of Radioactivity*

Spent nuclear fuel from commercial nuclear powerplants contains several hundred radionuclides when removed from the reactor. However, due to minor quantities, short half-lives, biological significance, and other factors, most of these are not important from a public health hazard standpoint. DOE has

Table A-7. Proposed Action spent nuclear fuel inventory (MTHM).[a]

Site	Fuel type[b]	1995 actual	1996-2011[c]	Total[d]	Equivalent assemblies
Arkansas Nuclear One	PWR	643	466	1,109	2,526
Beaver Valley	PWR	437	581	1,018	2,206
Big Rock Point	BWR	44	14	58	439
Braidwood	PWR	318	711	1,029	2,424
Browns Ferry	BWR	840	1,092	1,932	10,402
Brunswick	Both	448	448	896	4,410
Byron	PWR	404	664	1,068	2,515
Callaway	PWR	280	422	702	1,609
Calvert Cliffs	PWR	641	501	1,142	2,982
Catawba	PWR	465	683	1,148	2,677
Clinton	BWR	174	303	477	2,588
Comanche Peak	PWR	176	821	998	2,202
Cooper	BWR	175	277	452	2,435
Crystal River	PWR	280	232	512	1,102
D. C. Cook	PWR	777	656	1,433	3,253
Davis-Besse	PWR	243	262	505	1,076
Diablo Canyon	PWR	463	664	1,126	2,512
Dresden	BWR	1,557	590	2,146	11,602
Duane Arnold	BWR	258	208	467	2,545
Edwin I. Hatch	BWR	755	692	1,446	7,862
Fermi	BWR	155	368	523	2,898
Fort Calhoun	PWR	222	157	379	1,054
Ginna	PWR	282	180	463	1,234
Grand Gulf	BWR	349	506	856	4,771
H. B. Robinson	PWR	145	239	384	903
Haddam Neck	PWR	355	65	420	1,017
Humboldt Bay	BWR	29	--	29	390
Indian Point	PWR	678	486	1,164	2,649
James A. FitzPatrick/ Nine Mile Point	BWR	882	930	1,812	9,830
Joseph M. Farley	PWR	644	530	1,174	2,555
Kewaunee	PWR	282	169	451	1,172
La Crosse	BWR	38	--	38	333
La Salle	BWR	465	487	952	5,189
Limerick	BWR	432	711	1,143	6,203
Maine Yankee	PWR	454	82	536	1,421
McGuire	PWR	714	725	1,439	3,257
Millstone	Both	959	749	1,709	6,447
Monticello	BWR	147	280	426	2,324
North Anna	PWR	570	613	1,184	2,571
Oconee	PWR	1,098	767	1,865	4,028
Oyster Creek	BWR	374	325	699	3,824
Palisades	PWR	338	247	585	1,473
Palo Verde	PWR	556	1,118	1,674	4,082
Peach Bottom	BWR	908	645	1,554	8,413
Perry	BWR	178	274	452	2,470
Pilgrim	BWR	326	201	527	2,853
Point Beach	PWR	529	347	876	2,270
Prairie Island	PWR	518	348	866	2,315
Quad Cities	BWR	813	464	1,277	6,953
Rancho Seco	PWR	228	--[e]	228	493
River Bend	BWR	176	356	531	2,889
Salem/Hope Creek	Both	793	866	1,659	7,154
San Onofre	PWR	722	701	1,423	3,582
Seabrook	PWR	133	292	425	918
Sequoyah	PWR	452	570	1,023	2,218
Shearon Harris	Both	498	252	750	2,499
South Texas Project	PWR	290	722	1,012	1,871
St. Lucie	PWR	601	419	1,020	2,701
Summer	PWR	225	301	526	1,177
Surry	PWR	660	534	1,194	2,604
Susquehanna	BWR	628	648	1,276	7,172
Three Mile Island	PWR	311	236	548	1,180
Trojan	PWR	359	--	359	780
Turkey Point	PWR	616	458	1,074	2,355
Vermont Yankee	BWR	387	222	609	3,299
Vogtle	PWR	335	745	1,080	2,364
Columbia Generating Station	BWR	243	338	581	3,223
Waterford	PWR	253	247	500	1,217
Watts Bar	PWR	--	251	251	544
Wolf Creek	PWR	226	404	630	1,360
Yankee-Rowe	PWR	127	--	127	533
Zion	PWR	841	211	1,052	2,302
Totals		***31,926***	***31,074***	***63,000***	***218,700***

a. Source: DIRS 155725-CRWMS M&O (1998, all).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. Projected.
d. To convert metric tons to tons, multiply by 1.1023.
e. -- = no spent nuclear fuel production.

determined that 51 radionuclides represent all of the health-significant species that can contribute to a radiological dose if released in an accident. The derivation of the list of radionuclides of interest in terms of impacts to the public is described in Appendix H, Section H.2.1.4.1. Tables A-9 and A-10 list these radionuclides and their inventories for average pressurized-water and boiling-water reactor spent nuclear fuel assemblies. The inventories are presented at the average decay years for each of the assemblies.

Table A-11 combines the average inventories (curies per MTHM) with the projected totals (63,000 MTHM and 105,000 MTHM) to provide a total projected radionuclide inventory for the Proposed Action and additional modules.

Table A-8. Inventory Modules 1 and 2 spent nuclear fuel inventory (MTHM).[a]

Site	Fuel type[b]	1995 actual	1996-2046[c]	Total[d]	Equivalent assemblies
Arkansas Nuclear One	PWR	643	1,007	1,650	3,757
Beaver Valley	PWR	437	1,395	1,832	3,970
Big Rock Point	BWR	44	14	58	439
Braidwood	PWR	318	1,969	2,287	5,385
Browns Ferry	BWR	840	2,508	3,348	18,024
Brunswick	Both	448	992	1,440	7,355
Byron	PWR	404	1,777	2,181	5,139
Callaway	PWR	280	1,008	1,288	2,953
Calvert Cliffs	PWR	641	1,069	1,710	4,466
Catawba	PWR	465	1,752	2,217	5,168
Clinton	BWR	174	910	1,084	5,876
Comanche Peak	PWR	176	2,459	2,635	5,816
Cook	PWR	777	1,379	2,155	4,892
Cooper	BWR	175	587	762	4,106
Crystal River	PWR	280	525	805	1,734
Davis-Besse	PWR	243	582	825	1,757
Diablo Canyon	PWR	463	1,725	2,187	4,878
Dresden	BWR	1,557	984	2,541	13,740
Duane Arnold	BWR	258	434	692	3,776
Fermi	BWR	155	1,005	1,160	6,429
Fort Calhoun	PWR	222	312	534	1,485
Ginna	PWR	282	283	565	1,507
Grand Gulf	BWR	349	1,261	1,610	8,976
H. B. Robinson	PWR	145	364	509	1,197
Haddam Neck	PWR	355	65	420	1,017
Hatch	BWR	755	1,517	2,272	12,347
Humboldt Bay	BWR	29	--	29	390
Indian Point	PWR	678	1,005	1,683	3,787
James A. FitzPatrick/ Nine Mile Point	BWR	882	2,018	2,900	15,732
Joseph M. Farley	PWR	644	1,225	1,869	4,070
Kewaunee	PWR	282	330	612	1,591
La Crosse	BWR	38	--	38	333
La Salle	BWR	465	1,398	1,863	10,152
Limerick	BWR	432	1,958	2,390	12,967
Maine Yankee	PWR	454	82	536	1,421
McGuire	PWR	714	1,813	2,527	5,720
Millstone	Both	959	1,695	2,655	8,930

Site	Fuel type[b]	1995 actual	1996-2046[c]	Total[d]	Equivalent assemblies
Monticello	BWR	147	390	537	2,924
North Anna	PWR	570	1,384	1,955	4,246
Oconee	PWR	1,098	1,576	2,674	5,774
Oyster Creek	BWR	374	470	844	4,619
Palisades	PWR	338	395	733	1,845
Palo Verde	PWR	556	3,017	3,573	8,712
Peach Bottom	BWR	908	1,404	2,312	12,523
Perry	BWR	178	732	910	4,974
Point Beach	PWR	529	614	1,143	2,961
Prairie Island	PWR	518	692	1,210	3,234
Quad Cities	BWR	813	1,020	1,834	9,982
Pilgrim	BWR	326	444	770	4,170
Rancho Seco	PWR	228	--[e]	228	493
River Bend	BWR	176	956	1,132	6,153
Salem/Hope Creek	Both	793	2,452	3,245	11,584
San Onofre	PWR	722	1,321	2,043	5,144
Seabrook	PWR	133	831	964	2,083
Sequoyah	PWR	452	1,393	1,845	4,001
Shearon Harris	Both	498	707	1,205	3,535
South Texas Project	PWR	290	2,029	2,319	4,286
St. Lucie	PWR	601	1,010	1,611	4,265
Summer	PWR	225	732	958	2,141
Surry	PWR	660	1,029	1,689	3,682
Susquehanna	BWR	628	1,745	2,373	13,338
Three Mile Island	PWR	311	513	825	1,777
Trojan	PWR	359	--	359	780
Turkey Point	PWR	616	905	1,520	3,334
Vermont Yankee	BWR	387	434	822	4,451
Vogtle	PWR	335	2,122	2,458	5,378
Columbia Generating Station	BWR	243	924	1,167	6,476
Waterford	PWR	253	685	938	2,282
Watts Bar	PWR	--	893	893	1,937
Wolf Creek	PWR	226	1,052	1,278	2,759
Yankee-Rowe	PWR	127	--	127	533
Zion	PWR	841	211	1,052	2,302
Totals		***31,926***	***73,488***	***105,414***	***359,963***

a. Source: DIRS 155725-CRWMS M&O (1998, all).
b. PWR = pressurized-water reactor; BWR = boiling-water reactor.
c. Projected.
d. To convert metric tons to tons, multiply by 1.1023.
e. -- = no spent nuclear fuel production.

DOE used the fuel characteristics derived in Section A.2.1.5 and listed in Table A-6 to establish the fission product and radionuclide inventories of the pressurized-water and boiling-water reactor representative fuel assemblies used for accident analyses. For these analyses, DOE included a radionuclide contribution from activated corrosion products deposited on the surfaces of spent nuclear fuel assemblies during reactor operation. This material is called *crud*.

DOE used the fuel assembly surface concentration values in *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et. al. 2000, all) to develop the radioactive inventory from crud. The crud contains eight radionuclides. However, because all of these radionuclides except cobalt-60 decay rapidly, after storage (aging) for 5 years or longer, cobalt-60 is the only significant radionuclide remaining. The surface concentration values at discharge from the reactor range from 2 to 140 microcuries per square centimeter for pressurized-water reactor fuel assemblies and from 11 to 595 microcuries per square centimeter for boiling-water reactor assemblies, based on measurements of fuel rods (DIRS 152476-Sprung et al. 2000, p. 7-48; DIRS 103696-Sandoval 1991, all). Due to the wide range in concentration values and the limited number of measurements, DOE elected to use the maximum (cobalt-60) crud concentration numbers (DIRS 152476-Sprung et al. 2000, p. 7-48).

Table A-9. Radionuclide activity for average pressurized-water reactor fuel assemblies.[a,b]

Radionuclide[c]	Curies per assembly	Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	1.2×10^{2}	Antimony-125	2.6×10^{1}	Uranium-236	1.4×10^{-1}
Carbon-14	6.6×10^{-1}	Tin-126	4.5×10^{-1}	Uranium-238	1.4×10^{-1}
Chlorine-36	5.5×10^{-3}	Iodine-129	1.8×10^{-2}	Neptunium-237	2.4×10^{-1}
Iron-55	3.4×10^{0}	Cesium-134	4.4×10^{1}	Plutonium-238	1.9×10^{3}
Cobalt-60	2.2×10^{2}	Cesium-135	2.7×10^{-1}	Plutonium-239	1.8×10^{2}
Nickel-59	1.3×10^{0}	Cesium-137	3.4×10^{4}	Plutonium-240	2.8×10^{2}
Nickel-63	1.9×10^{2}	Promethium-147	1.3×10^{2}	Plutonium-241	2.4×10^{4}
Selenium-79	2.3×10^{-1}	Samarium-151	1.9×10^{2}	Plutonium-242	1.0×10^{0}
Krypton-85	1.1×10^{3}	Europium-154	9.6×10^{2}	Americium-241	1.6×10^{3}
Strontium-90	2.3×10^{4}	Europium-155	1.6×10^{2}	Americium-242/242m	1.1×10^{1}
Zirconium-93	1.2×10^{0}	Actinium-227	7.3×10^{-6}	Americium-243	1.4×10^{1}
Niobium-93m	8.1×10^{-1}	Thorium-230	1.4×10^{-4}	Curium-242	9.1×10^{0}
Niobium-94	6.0×10^{-1}	Protactinium-231	1.6×10^{-5}	Curium-243	9.7×10^{0}
Technetium-99	7.3×10^{0}	Uranium-232	2.1×10^{-2}	Curium-244	9.0×10^{2}
Ruthenium-106	3.3×10^{-2}	Uranium-233	3.1×10^{-5}	Curium-245	2.1×10^{-1}
Palladium-107	6.6×10^{-2}	Uranium-234	6.5×10^{-1}	Curium-246	4.7×10^{-2}
Cadmium-113m	1.1×10^{1}	Uranium-235	8.0×10^{-3}		

a. Source: DIRS 150276-CRWMS M&O (2000, p. VIII-3).
b. Burnup = 41,200 MWd/MTHM, enrichment = 3.75 percent, decay time = 23 years.
c. Half-lives are listed in Table A-11.

Table A-10. Radionuclide activity for average boiling-water reactor fuel assemblies.[a,b]

Radionuclide[c]	Curies per assembly	Isotope	Curies per assembly	Isotope	Curies per assembly
Hydrogen-3	4.2×10^{1}	Antimony-125	1.1×10^{1}	Uranium-236	4.5×10^{-2}
Carbon-14	2.9×10^{-1}	Tin-126	1.5×10^{-1}	Uranium-238	5.7×10^{-2}
Chlorine-36	2.1×10^{-3}	Iodine-129	6.1×10^{-3}	Neptunium-237	7.1×10^{-2}
Iron-55	9.5×10^{-1}	Cesium-134	1.6×10^{1}	Plutonium-238	6.0×10^{2}
Cobalt-60	6.5×10^{1}	Cesium-135	9.9×10^{-2}	Plutonium-239	6.0×10^{1}
Nickel-59	3.4×10^{-1}	Cesium-137	1.1×10^{4}	Plutonium-240	9.3×10^{1}
Nickel-63	4.5×10^{1}	Promethium-147	4.9×10^{1}	Plutonium-241	8.9×10^{3}
Selenium-79	7.7×10^{-2}	Samarium-151	6.6×10^{1}	Plutonium-242	4.0×10^{-1}
Krypton-85	3.7×10^{2}	Europium-154	3.2×10^{2}	Americium-241	6.1×10^{2}
Strontium-90	7.5×10^{3}	Europium-155	5.7×10^{1}	Americium-242/242m	4.7×10^{0}
Zirconium-93	4.6×10^{-1}	Actinium-227	2.6×10^{-6}	Americium-243	5.2×10^{0}
Niobium-93m	3.1×10^{-1}	Thorium-230	4.5×10^{-5}	Curium-242	3.9×10^{0}
Niobium-94	1.9×10^{-2}	Protactinium-231	5.4×10^{-6}	Curium-243	3.8×10^{0}
Technetium-99	2.4×10^{0}	Uranium-232	6.2×10^{-3}	Curium-244	3.5×10^{2}
Ruthenium-106	1.4×10^{-2}	Uranium-233	9.1×10^{-6}	Curium-245	7.9×10^{-2}
Palladium-107	2.4×10^{-2}	Uranium-234	2.1×10^{-1}	Curium-246	1.7×10^{-2}
Cadmium-113m	4.0×10^{0}	Uranium-235	2.6×10^{-3}		

a. Source: DIRS 150276-CRWMS M&O (2000, p. VIII-5).
b. Burnup = 33,600 MWd/MTHM, enrichment = 3.03 percent, decay time = 23 years.
c. Half-lives are listed in Table A-11.

Table A-11. Total projected radionuclide inventories[a,b] (page 1 of 2).

		Pressurized-water reactor			Boiling-water reactor			Grand totals (curies)	
			Total curies			Total curies			
Isotope	Half life (yrs.)[c]	Curies per MTHM[d]	Proposed Action	Additional modules	Curies per MTHM	Proposed Action	Additional modules	Proposed Action	Additional modules
Hydrogen-3	12.3	2.5×10^{2}	1.0×10^{7}	1.7×10^{7}	2.3×10^{2}	5.1×10^{6}	8.5×10^{6}	1.6×10^{7}	2.6×10^{7}
Carbon-14	5.7×10^{3}	1.4×10^{0}	5.9×10^{4}	9.8×10^{4}	1.6×10^{0}	3.6×10^{4}	6.0×10^{4}	9.5×10^{4}	1.6×10^{5}
Chlorine-36	3.0×10^{5}	1.2×10^{-2}	4.9×10^{2}	8.2×10^{2}	1.2×10^{-2}	2.6×10^{2}	4.3×10^{2}	7.5×10^{2}	1.2×10^{3}
Iron-55	2.7	7.4×10^{0}	3.0×10^{5}	5.1×10^{5}	5.3×10^{0}	1.2×10^{5}	1.9×10^{5}	4.2×10^{5}	7.0×10^{5}
Cobalt-60	5.3	4.7×10^{2}	1.9×10^{7}	3.2×10^{7}	3.6×10^{2}	8.0×10^{6}	1.3×10^{7}	2.7×10^{7}	4.5×10^{7}
Nickel-59	7.6×10^{4}	2.9×10^{0}	1.2×10^{5}	2.0×10^{5}	1.9×10^{0}	4.1×10^{4}	6.9×10^{4}	1.6×10^{5}	2.7×10^{5}
Nickel-63	1.0×10^{2}	4.0×10^{2}	1.7×10^{7}	2.8×10^{7}	2.5×10^{2}	5.5×10^{6}	9.2×10^{6}	2.2×10^{7}	3.7×10^{7}
Selenium-79	6.5×10^{4}	5.1×10^{-1}	2.1×10^{4}	3.5×10^{4}	4.3×10^{-1}	9.4×10^{3}	1.6×10^{4}	3.0×10^{4}	5.0×10^{4}
Krypton-85	10.7	2.5×10^{3}	1.0×10^{8}	1.7×10^{8}	2.1×10^{3}	4.6×10^{7}	7.6×10^{7}	1.5×10^{8}	2.5×10^{8}
Strontium-90	29	5.1×10^{4}	2.1×10^{9}	3.5×10^{9}	4.2×10^{4}	9.2×10^{8}	1.5×10^{9}	3.0×10^{9}	5.0×10^{9}
Zirconium-93	1.5×10^{6}	2.6×10^{0}	1.1×10^{5}	1.8×10^{5}	2.6×10^{0}	5.7×10^{4}	9.5×10^{4}	1.6×10^{5}	2.7×10^{5}
Niobium-93m	16	1.8×10^{0}	7.2×10^{4}	1.2×10^{5}	1.7×10^{0}	3.9×10^{4}	6.4×10^{4}	1.1×10^{5}	1.8×10^{5}
Niobium-94	2.4×10^{4}	1.3×10^{0}	5.3×10^{4}	8.9×10^{4}	1.1×10^{-1}	2.3×10^{3}	3.9×10^{3}	5.6×10^{4}	9.3×10^{4}
Technetium-99	2.1×10^{5}	1.6×10^{1}	6.5×10^{5}	1.1×10^{6}	1.4×10^{1}	3.0×10^{5}	5.0×10^{5}	9.5×10^{5}	1.6×10^{6}
Ruthenium-106	1.0	7.2×10^{-2}	3.0×10^{3}	4.9×10^{3}	7.9×10^{-2}	1.8×10^{3}	2.9×10^{3}	4.7×10^{3}	7.9×10^{3}
Palladium-107	6.5×10^{6}	1.4×10^{-1}	5.9×10^{3}	9.8×10^{3}	1.3×10^{-1}	2.9×10^{3}	4.8×10^{3}	8.8×10^{3}	1.5×10^{4}
Cadmium-113m	14	2.5×10^{1}	1.0×10^{6}	1.7×10^{6}	2.2×10^{1}	4.9×10^{5}	8.1×10^{5}	1.5×10^{6}	2.5×10^{6}
Antimony-125	2.8	5.6×10^{1}	2.3×10^{6}	3.9×10^{6}	5.9×10^{1}	1.3×10^{6}	2.2×10^{6}	3.6×10^{6}	6.0×10^{6}
Tin-126	1.0×10^{6}	9.8×10^{-1}	4.0×10^{4}	6.7×10^{4}	8.5×10^{-1}	1.9×10^{4}	3.1×10^{4}	5.9×10^{4}	9.8×10^{4}
Iodine-129	1.7×10^{7}	3.9×10^{-2}	1.6×10^{3}	2.7×10^{3}	3.4×10^{-2}	7.5×10^{2}	1.2×10^{3}	2.4×10^{3}	3.9×10^{3}
Cesium-134	2.1	9.5×10^{1}	3.9×10^{6}	6.5×10^{6}	8.7×10^{1}	1.9×10^{6}	3.2×10^{6}	5.8×10^{6}	9.7×10^{6}
Cesium-135	2.3×10^{6}	5.8×10^{-1}	2.4×10^{4}	3.9×10^{4}	5.5×10^{-1}	1.2×10^{4}	2.0×10^{4}	3.6×10^{4}	6.0×10^{4}
Cesium-137	30	7.5×10^{4}	3.1×10^{9}	5.1×10^{9}	6.4×10^{4}	1.4×10^{9}	2.3×10^{9}	4.5×10^{9}	7.4×10^{9}
Promethium-147	2.6	2.8×10^{2}	1.2×10^{7}	1.9×10^{7}	2.7×10^{2}	6.0×10^{6}	1.0×10^{7}	1.8×10^{7}	2.9×10^{7}
Samarium-151	90	4.2×10^{2}	1.7×10^{7}	2.9×10^{7}	3.7×10^{2}	8.1×10^{6}	1.4×10^{7}	2.5×10^{7}	4.2×10^{7}
Europium-154	8.6	2.1×10^{3}	8.5×10^{7}	1.4×10^{8}	1.8×10^{3}	3.9×10^{7}	6.5×10^{7}	1.2×10^{8}	2.1×10^{8}
Europium-155	4.8	3.6×10^{2}	1.5×10^{7}	2.4×10^{7}	3.2×10^{2}	7.0×10^{6}	1.2×10^{7}	2.2×10^{7}	3.6×10^{7}
Actinium-227	2.2	1.6×10^{-5}	6.5×10^{-1}	1.1×10^{0}	1.4×10^{-5}	3.1×10^{-1}	5.2×10^{-1}	9.7×10^{-1}	1.6×10^{0}
Thorium-230	7.5×10^{4}	3.0×10^{-4}	1.2×10^{1}	2.0×10^{1}	2.5×10^{-4}	5.5×10^{0}	9.1×10^{0}	1.8×10^{1}	2.9×10^{1}
Protactinium-231	3.3×10^{4}	3.4×10^{-5}	1.4×10^{0}	2.3×10^{0}	3.0×10^{-5}	6.7×10^{-1}	1.1×10^{0}	2.1×10^{0}	3.4×10^{0}
Uranium-232	69	4.5×10^{-2}	1.9×10^{3}	3.1×10^{3}	3.4×10^{-2}	7.5×10^{2}	1.3×10^{3}	2.6×10^{3}	4.3×10^{3}
Uranium-233	1.6×10^{5}	6.8×10^{-5}	2.8×10^{0}	4.7×10^{0}	5.1×10^{-5}	1.1×10^{0}	1.9×10^{0}	3.9×10^{0}	6.5×10^{0}
Uranium-234	2.5×10^{5}	1.4×10^{0}	5.8×10^{4}	9.6×10^{4}	1.2×10^{0}	2.6×10^{4}	4.3×10^{4}	8.4×10^{4}	1.4×10^{5}

Table A-11. Total projected radionuclide inventories[a,b] (page 1 of 2).

		Pressurized-water reactor			Boiling-water reactor				
			Total curies			Total curies		Grand totals (curies)	
Isotope	Half life (yrs.)[c]	Curies per MTHM[d]	Proposed Action	Additional modules	Curies per MTHM	Proposed Action	Additional modules	Proposed Action	Additional modules
Uranium-235	7.0×10^{8}	1.7×10^{-2}	7.1×10^{2}	1.2×10^{3}	1.4×10^{-2}	3.2×10^{2}	5.3×10^{2}	1.0×10^{3}	1.7×10^{3}
Uranium-236	2.3×10^{7}	3.1×10^{-1}	1.3×10^{4}	2.1×10^{4}	2.5×10^{-1}	5.5×10^{3}	9.1×10^{3}	1.8×10^{4}	3.0×10^{4}
Uranium-238	4.5×10^{9}	3.1×10^{-1}	1.3×10^{4}	2.1×10^{4}	3.2×10^{-1}	7.0×10^{3}	1.2×10^{4}	2.0×10^{4}	3.3×10^{4}
Neptunium-237	2.1×10^{6}	5.2×10^{-1}	2.1×10^{4}	3.5×10^{4}	4.0×10^{-1}	8.7×10^{3}	1.5×10^{4}	3.0×10^{4}	5.0×10^{4}
Plutonium-238	88	4.1×10^{3}	1.7×10^{8}	2.8×10^{8}	3.3×10^{3}	7.4×10^{7}	1.2×10^{8}	2.4×10^{8}	4.0×10^{8}
Plutonium-239	2.4×10^{4}	4.0×10^{2}	1.6×10^{7}	2.7×10^{7}	3.3×10^{2}	7.3×10^{6}	1.2×10^{7}	2.4×10^{7}	4.0×10^{7}
Plutonium-240	6.5×10^{3}	6.0×10^{2}	2.5×10^{7}	4.1×10^{7}	5.2×10^{2}	1.1×10^{7}	1.9×10^{7}	3.6×10^{7}	6.0×10^{7}
Plutonium-241	14	5.2×10^{4}	2.1×10^{9}	3.5×10^{9}	5.0×10^{4}	1.1×10^{9}	1.8×10^{9}	3.2×10^{9}	5.3×10^{9}
Plutonium-242	3.8×10^{5}	2.2×10^{0}	9.2×10^{4}	1.5×10^{5}	2.2×10^{0}	4.9×10^{4}	8.2×10^{4}	1.4×10^{5}	2.3×10^{5}
Americium-241	4.3×10^{2}	3.6×10^{3}	1.5×10^{8}	2.4×10^{8}	3.4×10^{3}	7.4×10^{7}	1.2×10^{8}	2.2×10^{8}	3.7×10^{8}
Americium-242/242m	1.4×10^{2}	2.4×10^{1}	9.8×10^{5}	1.6×10^{6}	2.6×10^{1}	5.7×10^{5}	9.5×10^{5}	1.6×10^{6}	2.6×10^{6}
Americium-243	7.4×10^{3}	3.0×10^{1}	1.2×10^{6}	2.0×10^{6}	2.9×10^{1}	6.4×10^{5}	1.1×10^{6}	1.9×10^{6}	3.1×10^{6}
Curium-242	0.45	2.0×10^{1}	8.1×10^{5}	1.4×10^{6}	2.1×10^{1}	4.7×10^{5}	7.9×10^{5}	1.3×10^{6}	2.1×10^{6}
Curium-243	29	2.1×10^{1}	8.6×10^{5}	1.4×10^{6}	2.1×10^{1}	4.6×10^{5}	7.7×10^{5}	1.3×10^{6}	2.2×10^{6}
Curium-244	18	1.9×10^{3}	8.0×10^{7}	1.3×10^{8}	1.9×10^{3}	4.3×10^{7}	7.1×10^{7}	1.2×10^{8}	2.0×10^{8}
Curium-245	8.5×10^{3}	4.6×10^{-1}	1.9×10^{4}	3.2×10^{4}	4.4×10^{-1}	9.7×10^{3}	1.6×10^{4}	2.9×10^{4}	4.8×10^{4}
Curium-246	4.8×10^{3}	1.0×10^{-1}	4.2×10^{3}	7.0×10^{3}	9.5×10^{-2}	2.1×10^{3}	3.5×10^{3}	6.3×10^{3}	1.0×10^{4}

a. Source: Compilation of Tables A-9 and A-10.

b. The radionuclides listed are those used in the most recent repository preclosure safety assessment (DIRS 150276-CRWMS M&O 2000, all) and include all those used in the postclosure impacts analysis (Chapter 5). The radionuclides listed have been revised from the list in the Draft EIS; DOE has determined that the revisions to the list (including both omissions and additions) resulted in no change to the preclosure accident impacts.

c. Half-life is defined as the time in which half of the atoms of a radioactive substance decay to another nuclear form.

d. MTHM = metric tons of heavy metal; 0.18 MTHM per boiling-water reactor assembly and 0.46 MTHM per pressurized-water reactor assembly.

Converting the surface concentration values to total assembly inventory requires estimates of the surface area of the assembly. Conservative estimated surface area values for pressurized-water and boiling-water reactor assemblies currently in operation are 450,000 square centimeters (1,200 square feet) for pressurized-water reactor assemblies and 170,000 square centimeters (460 square feet) for boiling-water reactor assemblies (DIRS 150276-CRWMS M&O 2000, p. VIII-4, 5).

The resulting cobalt-60 crud inventories at discharge from the reactor, therefore, are 450,000 square centimeters × 140 microcuries per square centimeter = 63 curies for pressurized-water reactor assemblies and 170,000 square centimeters × 595 microcuries per square centimeter = 100 curies for boiling-water reactor assemblies. Because these values would be at the time of discharge of the fuel from the reactor, the inventories must be corrected for radioactive decay. The half-life (time for half of the radionuclide to decay) of cobalt-60 is 5.27 years. Because the representative fuel assemblies (see Table A-6) are 14 years old for boiling-water reactor fuel and 15 years old for pressurized-water reactor fuel, the cobalt-60 inventories must be reduced by 2.66 (14/5.27) half-lives for boiling-water reactor fuel and 2.85 (15/5.27) half-lives for the pressurized-water reactor fuel. The resulting inventories are then $100/(2)^{2.66}$ = 16 curies per boiling-water reactor assembly and $63/(2)^{2.85}$ = 9 curies per pressurized-water reactor assembly. Because DOE used maximum values for both the surface concentration and surface area, these results are conservative.

Tables A-12 and A-13 list the radionuclide inventories for the representative pressurized-water and boiling-water reactor spent nuclear fuel assemblies, respectively. The list of radionuclides is modified from DIRS 150276-CRWMS M&O (2000, p. VIII-3), which DOE used for preclosure accident analyses. For accident evaluation, the location of the radionuclides on and in the fuel assemblies can be important, so these tables provide this information (DIRS 152476-Sprung et al. 2000, all). Some of the radionuclides are produced by neutron activation of stable elements in the structures of the fuel assembly; these are listed in the Location column. A few radionuclides reside in the gap between the fuel pellet and the cladding; these are also listed in the Location column. The majority of the radionuclides are in the fuel pellets, as listed in the tables, and a few are in both the fuel pellet and the fuel clad gap.

A.2.1.5.3 *Chemical Composition*

Commercial spent nuclear fuel consists of the uranium oxide fuel itself (including actinides, fission products, etc.), the cladding, and the assembly hardware.

Typical pressurized-water and boiling-water reactor fuels consist of uranium dioxide fuel pellets with a zirconium alloy cladding. Some assemblies, however, are clad in stainless-steel 304. These assemblies have been discharged from Haddam Neck, Yankee-Rowe, Indian Point, San Onofre, and LaCrosse and comprise 1.15 percent of the MTHM included in the Proposed Action. Table A-14 lists the number sites, storage locations, and fuel assemblies and MTHM discharged.

Tables A-15 and A-16 list the postirradiation elemental distributions for typical fuels. The data in these tables include the fuel, cladding material, and assembly hardware.

A.2.1.5.4 *Thermal Output*

Heat generation rates are available as a function of spent fuel type, enrichment, burnup, and decay time in the Light-Water Reactor Radiological Database, which is an integral part of the *Characteristics of Potential Repository Wastes* (DIRS 102588-DOE 1992, p. 1.1-1). Table A-17 lists the thermal profiles for the average pressurized-water reactor and boiling-water reactor assemblies from the Light-Water Reactor Radiological Database. For the EIS analysis, the typical thermal profile, applied across the proposed inventory, yields a good approximation of the expected thermal load in the repository. Figure A-6 shows these profiles as a function of time.

Table A-12. Radionuclide activity for representative pressurized-water reactor fuel assemblies.[a,b]

Radionuclide[c]	Curies per assembly	Location	Radionuclide[c]	Curies per assembly	Location
Hydrogen-3	2.0×10^{2}	Fuel clad gap	Samarium-151	2.4×10^{2}	Fuel pellet
Carbon-14	3.0×10^{-1}	Fuel clad gap	Europium-154	1.5×10^{3}	Fuel pellet
Chlorine-36	6.3×10^{-3}	Fuel clad gap	Europium-155	2.2×10^{2}	Fuel pellet
Iron-55	4.0×10^{1}	Structures	Actinium-227	1.3×10^{-5}	Fuel pellet
Cobalt-60	1.1×10^{3}	Structures	Thorium-230	9.9×10^{-5}	Fuel pellet
Cobalt-60	8.8×10^{0}	Surfaces (crud)	Protactinium-231	3.3×10^{-5}	Fuel pellet
Nickel-59	1.9×10^{0}	Structures	Uranium-232	2.4×10^{-2}	Fuel pellet
Nickel-63	2.5×10^{2}	Structures	Uranium-233	3.2×10^{-5}	Fuel pellet
Selenium-79	4.6×10^{-2}	Fuel pellet	Uranium-234	6.7×10^{-1}	Fuel pellet
Krypton-85	2.2×10^{3}	Fuel clad gap	Uranium-235	8.8×10^{-3}	Fuel pellet
Strontium-90	3.6×10^{4}	Fuel pellet, gap	Uranium-236	1.9×10^{-1}	Fuel pellet
Yttrium-90[d]	3.6×10^{4}	Fuel pellet, gap	Uranium-238	1.4×10^{-1}	Fuel pellet
Zirconium-93	9.8×10^{-1}	Fuel pellet	Neptunium-237	2.5×10^{-1}	Fuel pellet
Niobium-93m	1.9×10^{1}	Fuel pellet	Plutonium-238	2.6×10^{3}	Fuel pellet
Niobium-94	8.1×10^{-1}	Fuel pellet	Plutonium-239	1.8×10^{2}	Fuel pellet
Technetium-99	9.1×10^{0}	Fuel pellet	Plutonium-240	3.1×10^{2}	Fuel pellet
Ruthenium-106	1.1×10^{1}	Fuel pellet	Plutonium-241	3.9×10^{4}	Fuel pellet
Palladium-107	7.8×10^{-2}	Fuel pellet	Plutonium-242	1.5×10^{0}	Fuel pellet
Cadmium-113m	1.2×10^{1}	Fuel pellet	Americium-241	1.5×10^{3}	Fuel pellet
Tin-126	3.7×10^{-1}	Fuel pellet	Americium-242m	7.2×10^{0}	Fuel pellet
Antimony-125	1.2×10^{2}	Fuel pellet	Americium-243	2.0×10^{1}	Fuel pellet
Iodine-129	2.2×10^{-2}	Fuel clad gap	Curium-242	5.9×10^{0}	Fuel pellet
Cesium-134	7.2×10^{2}	Fuel pellet, gap	Curium-243	1.3×10^{1}	Fuel pellet
Cesium-135	3.8×10^{-1}	Fuel pellet, gap	Curium-244	1.8×10^{3}	Fuel pellet
Cesium-137	5.2×10^{4}	Fuel pellet, gap	Curium-245	2.9×10^{-1}	Fuel pellet
Barium-137m[d]	5.2×10^{4}	Fuel pellet, gap	Curium-246	9.1×10^{-2}	Fuel pellet
Promethium-147	1.7×10^{3}	Fuel pellet			

a. Source: DIRS 156919-Ikenberry (2001, all).
b. Burnup = 50,000 MWd/MTHM, enrichment = 4.3 percent, decay time = 15 years.
c. Half-lives are listed in Table A-11.
d. Barium-137m and yttrium-90 are included and are assumed to be in equilibrium with cesium-137 and strontium-90, respectively.

A.2.1.5.5 *Physical Parameters*

Table A-18 lists reference characteristics of typical pressurized-water and boiling-water reactor fuel assemblies. These data are from the Integrated Data Base Report (DIRS 101815-DOE 1997, p. 1-8) and reflect characteristics of unirradiated assemblies.

For additional details, the Light-Water Reactor Assembly Database contains individual physical descriptions of the fuel assemblies and fuel pins. The Light-Water Reactor Nonfuel Assembly Hardware Database contains physical and radiological descriptions of nonfuel assembly hardware. These databases are integral parts of the *Characteristics of Potential Repository Wastes* (DIRS 102588-DOE 1992, Section 2.8).

A.2.2 DOE SPENT NUCLEAR FUEL

A.2.2.1 Background

At present, DOE stores most of its spent nuclear fuel at three primary locations: the Hanford Site in Washington State, the Idaho National Engineering and Environmental Laboratory in Idaho, and the

Table A-13. Radionuclide activity for representative boiling-water reactor fuel assemblies.[a,b,c]

Radionuclide[c]	Curies per assembly	Location	Isotope	Curies per assembly	Location
Hydrogen-3	6.6×10^{1}	Fuel clad gap	Samarium-151	5.3×10^{1}	Fuel pellet
Carbon-14	1.6×10^{-1}	Fuel clad gap	Europium-154	3.9×10^{2}	Fuel pellet
Chlorine-36	2.6×10^{-3}	Fuel clad gap	Europium-155	7.5×10^{1}	Fuel pellet
Iron-55	1.6×10^{1}	Structures	Actinium-227	0	Fuel pellet
Cobalt-60	1.7×10^{2}	Structures	Thorium-230	3.3×10^{-5}	Fuel pellet
Cobalt-60	1.6×10^{1}	Surfaces (crud)	Protactinium-231	1.2×10^{-5}	Fuel pellet
Nickel-59	4.5×10^{-1}	Structures	Uranium-232	4.6×10^{-3}	Fuel pellet
Nickel-63	5.7×10^{1}	Structures	Uranium-233	0	Fuel pellet
Selenium-79	1.4×10^{-2}	Fuel pellet	Uranium-234	2.1×10^{-1}	Fuel pellet
Krypton-85	7.0×10^{2}	Fuel clad gap	Uranium-235	2.4×10^{-3}	Fuel pellet
Strontium-90	1.1×10^{4}	Fuel pellet, gap	Uranium-236	5.6×10^{-2}	Fuel pellet
Yttrium-90[d]	1.1×10^{4}	Fuel pellet, gap	Uranium-238	5.7×10^{-2}	Fuel pellet
Zirconium-93	3.0×10^{-1}	Fuel pellet	Neptunium-237	6.0×10^{-2}	Fuel pellet
Niobium-93m	5.0×10^{-1}	Fuel pellet	Plutonium-238	5.7×10^{-2}	Fuel pellet
Niobium-94	1.7×10^{-2}	Fuel pellet	Plutonium-239	4.8×10^{1}	Fuel pellet
Technetium-99	2.9×10^{0}	Fuel pellet	Plutonium-240	1.0×10^{3}	Fuel pellet
Ruthenium-106	4.9×10^{0}	Fuel pellet	Plutonium-241	1.0×10^{4}	Fuel pellet
Palladium-107	2.4×10^{-2}	Fuel pellet	Plutonium-242	4.6×10^{-1}	Fuel pellet
Cadmium-113m	3.5×10^{0}	Fuel pellet	Americium-241	3.7×10^{2}	Fuel pellet
Tin-126	1.1×10^{-1}	Fuel pellet	Americium-242m	2.1×10^{0}	Fuel pellet
Antimony-125	4.3×10^{1}	Fuel pellet	Americium-243	4.8×10^{0}	Fuel pellet
Iodine-129	6.7×10^{-3}	Fuel clad gap	Curium-242	1.7×10^{0}	Fuel pellet
Cesium-134	2.3×10^{2}	Fuel pellet, gap	Curium-243	2.9×10^{0}	Fuel pellet
Cesium-135	1.3×10^{-1}	Fuel pellet, gap	Curium-244	3.5×10^{2}	Fuel pellet
Cesium-137	1.6×10^{4}	Fuel pellet, gap	Curium-245	3.6×10^{-2}	Fuel pellet
Barium-137m[d]	1.6×10^{4}	Fuel pellet, gap	Curium-246	1.8×10^{-2}	Fuel pellet
Promethium-147	6.6×10^{2}	Fuel pellet			

a. Source: DIRS 156919-Ikenberry (2001, all).
b. Burnup = 40,000 MWd/MTHM, enrichment = 3.5 percent, decay time = 14 years.
c. Half-lives are listed in Table A-11.
d. Barium-137m and yttrium-90 are included and are assumed to be in equilibrium with cesium-137 and strontium-90, respectively.

Table A-14. Stainless-steel-clad spent nuclear fuel inventory.[a]

Discharging reactors	Storage locations	Assemblies	MTHM[b]
5	6	2,187	727

a. Source: DIRS 104353-Cole (1998, all).
b. MTHM = metric tons of heavy metal.

Savannah River Site in South Carolina. Some DOE spent nuclear fuel is stored at the Fort St. Vrain dry storage facility in Colorado. DOE issued the *Record of Decision – Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* on June 1, 1995 (DIRS 103205-DOE 1995, all) and amended it in March 1996 (DIRS 147933-DOE 1996, all). The Record of Decision and its amendment specify three primary locations as storage sites for DOE spent nuclear fuel. With the exception of Fort St. Vrain, which will retain its spent nuclear fuel in dry storage, DOE will ship all its spent nuclear fuel from other sites to one of the three primary sites for storage and preparation for ultimate disposition.

Table A-15. Elemental distribution of average pressurized-water reactor fuel.[a]

Element	Grams per assembly[b]	Percent total[c]	Element	Grams per assembly[b]	Percent total[c]
Aluminum	47	0.01	Oxygen	62,000	9.35
Americium	600	0.09	Palladium	790	0.12
Barium	1,200	0.18	Phosphorus	85	0.01
Cadmium	77	0.01	Plutonium	4,600	0.69
Carbon	77	0.01	Praseodymium	610	0.09
Cerium	1,300	0.20	Rhodium	230	0.04
Cesium	1,100	0.17	Rubidium	200	0.03
Chromium	4,300	0.65	Ruthenium	1,200	0.18
Cobalt	38	0.01	Samarium	470	0.07
Europium	72	0.01	Silicon	170	0.03
Gadolinium	81	0.01	Silver	40	0.01
Iodine	130	0.02	Strontium	330	0.05
Iron	12,000	1.85	Technetium	420	0.06
Krypton	190	0.03	Tellurium	270	0.04
Lanthanum	670	0.10	Tin	1,900	0.29
Manganese	330	0.05	Titanium	51	0.01
Molybdenum	2,000	0.31	Uranium	440,000	65.78
Neodymium	2,200	0.33	Xenon	2,900	0.43
Neptunium	330	0.05	Yttrium	250	0.04
Nickel	5,000	0.75	Zirconium	120,000	17.77
Niobium	330	0.05			
Nitrogen	49	0.01	***Totals***	***668,637***	***99.99***

a. Source: DIRS 102588-DOE (1992, p. 1.1-1).
b. To convert grams to ounces, multiply by 0.035274.
c. Table only includes elements that constitute at least 0.01 percent of the total; therefore, the total of the percentage column is slightly less than 100 percent.

During the last four decades, DOE and its predecessor agencies have generated approximately 250 varieties of spent nuclear fuel from weapons production, nuclear propulsion, and research missions. A method described by (DIRS 104385-Fillmore 1998, all) allows grouping of these many varieties of spent nuclear fuel into 16 categories for the repository Total System Performance Assessment. The grouping method uses regulatory requirements to identify the parameters that would affect the performance of DOE spent nuclear fuel in the repository and meet analysis needs for the repository License Application. Three fuel parameters (fuel matrix, fuel compound, and cladding condition) would influence repository performance behavior. The methodology categorizes the characteristics of a select number of fuel types either bound or represent a particular characteristic of the whole category. Table A-19 lists these spent nuclear fuel categories, which continue to provide an accurate description of the DOE fuel characteristics for this Final EIS (DIRS 156369-Arenaz 2001, all).

Table A-19 includes sodium-bonded fuel (Category 14). DOE issued a Record of Decision for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel in September 2000. Electrometallurgical treatment, the preferred alternative, was chosen for EBR-II reactor fuel and other selected small lots. Fermi blanket fuel may be treated by the electrometallurgical process but the final decision has been deferred. Section A.2.3, which covers data associated with high-level radioactive waste, includes data on waste produced from the treatment of all Category 14 spent nuclear fuel (DIRS 104356-Dirkmaat 1997, p. 7). Therefore, this category is not considered as spent nuclear fuel in the EIS.

Table A-16. Elemental distribution of average boiling-water reactor fuel.[a]

Element	Grams per assembly[b]	Percent total[c]	Element	Grams per assembly[b]	Percent total[c]
Aluminum	31	0.01	Nitrogen	25	0.01
Americium	220	0.07	Oxygen	25,000	7.82
Barium	390	0.12	Palladium	270	0.09
Cadmium	27	0.01	Plutonium	1,500	0.48
Carbon	36	0.01	Praseodymium	200	0.06
Cerium	430	0.14	Rhodium	79	0.03
Cesium	390	0.12	Rubidium	64	0.02
Chromium	1,900	0.60	Ruthenium	410	0.13
Cobalt	26	0.01	Samarium	160	0.05
Europium	24	0.01	Silicon	80	0.03
Gadolinium	310	0.10	Strontium	110	0.03
Iodine	43	0.01	Technetium	140	0.04
Iron	5,100	1.63	Tellurium	91	0.03
Krypton	62	0.02	Tin	1,600	0.50
Lanthanum	220	0.07	Titanium	83	0.03
Manganese	160	0.05	Uranium	170,000	55.35
Molybdenum	630	0.20	Xenon	950	0.30
Neodymium	730	0.23	Yttrium	81	0.03
Neptunium	97	0.03	Zirconium	96,000	30.52
Nickel	3,000	0.94			
Niobium	29	0.01	***Totals***	***310,698***	***99.94***

a. Source: DIRS 102588-DOE (1992, p. 1.1-1).
b. To convert grams to ounces, multiply by 0.035274.
c. Table only includes elements that contribute at least 0.01 percent of the total; therefore, the total of the percentage column is slightly less than 100 percent.

Table A-17. Average assembly thermal profiles.[a]

Years after discharge	Pressurized-water reactor		Boiling-water reactor	
	W/MTHM[b]	W/assembly[c]	W/MTHM	W/assembly[d]
1	10,500	4,800	8,400	1,500
3	3,700	1,700	3,000	550
5	2,200	1,000	1,800	340
10	1,500	670	1,200	220
25	990	450	820	150
30	920	420	770	140
50	670	310	570	100
100	370	170	320	58
300	160	73	140	26
500	120	53	100	19
1,000	66	31	58	11
2,000	35	16	30	5
5,000	22	10	19	3
10,000	16	8	13	3

a. Source: DIRS 102588-DOE (1992, p. 1.1-1).
b. W/MTHM = watts per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.
c. W/assembly = watts per assembly; assumes 0.46 MTHM per assembly.
d. Assumes 0.18 MTHM per assembly.

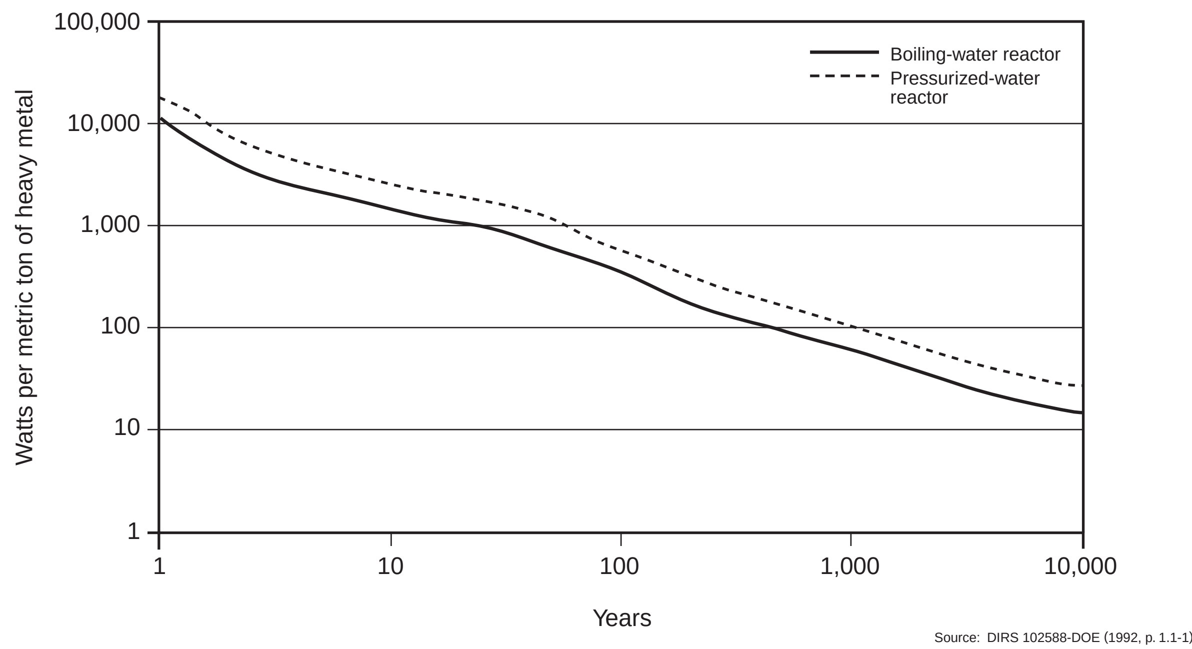


Figure A-6. Average thermal profiles over time.

Table A-18. Reference characteristics for average commercial spent nuclear fuel assemblies.[a]

Characteristics[b]	Boiling-water reactor	Pressurized-water reactor
Overall assembly length (meters)	4.5	4.1
Cross section (centimeters)	14 × 14	21 × 21
Fuel rod length (meters)	4.1	3.9
Active fuel height (meters)	3.8	3.7
Fuel rod outer diameter (centimeters)	1.3	0.95
Fuel rod array	8 × 8	17 × 17
Fuel rods per assembly	63	264
Assembly total weight (kilograms)	320	660
Uranium per assembly (kilograms)	180	460
Uranium oxide per assembly (kilograms)	210	520
Zirconium alloy per assembly (kilograms)	100[c]	110[d]
Hardware per assembly (kilograms)	8.6[e]	26[f]
Nominal volume per assembly (cubic meters)	0.086[g]	0.19[g]

a. Source: DIRS 101815-DOE (1997, p. 1-8).
b. To convert meters to feet, multiply by 3.2808; to convert centimeters to inches, multiply by 0.3937; to convert kilograms to pounds, multiply by 2.2046; to convert cubic meters to cubic feet, multiply by 35.314.
c. Includes zirconium alloy fuel rod spacers and fuel channels.
d. Includes zirconium alloy control rod guide thimbles.
e. Includes stainless-steel tie plates, Inconel springs, and plenum springs.
f. Includes stainless-steel nozzles and Inconel-718 grids.
g. Based on overall outside dimension; includes spacing between the stacked fuel rods of the assembly.

A.2.2.2 Sources

The DOE National Spent Fuel Program maintains a spent nuclear fuel data base (DIRS 153072-Wheatley 2000, all). Table A-19 provides a brief description of each of the fuel categories and a typical fuel. Section A.2.2.5.3 provides more detail on the chemical makeup of each category.

Table A-19. DOE spent nuclear fuel categories.[a,b,c]

	DOE SNF category	Typically from	Description of fuel
1.	Uranium metal	N-Reactor	Uranium metal fuel compounds with aluminum or zirconium alloy cladding
2.	Uranium-zirconium	HWCTR	Uranium alloy fuel compounds with zirconium alloy cladding
3.	Uranium-molybdenum	Fermi	Uranium-molybdenum alloy fuel compounds with zirconium alloy cladding
4.	Uranium oxide, intact	Commercial PWR	Uranium oxide fuel compounds with zirconium alloy or stainless-steel cladding in fair to good condition
5.	Uranium oxide, failed/ declad/aluminum clad	TMI core debris	Uranium oxide fuel compounds: (1) without cladding; (2) clad with zirconium alloy, Hastelloy, nickel-chromium, or stainless steel in poor or unknown condition; or (3) nondegraded aluminum clad
6.	Uranium-aluminide	ATR	Uranium-aluminum alloy fuel compounds with aluminum cladding
7.	Uranium-silicide	FRR MTR	Uranium silicide fuel compounds with aluminum cladding
8.	Thorium/uranium carbide, high-integrity	Fort St. Vrain	Thorium/uranium carbide fuel compounds with graphite cladding in good condition
9.	Thorium/uranium carbide, low-integrity	Peach Bottom	Thorium/uranium carbide fuel compounds with graphite cladding in unknown condition
10.	Plutonium/uranium carbide, nongraphite	FFTF carbide	Uranium carbide or plutonium-uranium carbide fuel compounds with or without stainless-steel cladding
11.	Mixed oxide	FFTF oxide	Plutonium/uranium oxide fuel compounds in zirconium alloy, stainless-steel, or unknown cladding
12.	Uranium/thorium oxide	Shippingport LWBR	Uranium/thorium oxide fuel compounds with zirconium alloy or stainless-steel cladding
13.	Uranium-zirconium hydride	TRIGA	Uranium-zirconium hydride fuel compounds with or without Incalloy, stainless-steel, or aluminum cladding
14.	Sodium-bonded	EBR-II driver and blanket, Fermi-I blanket	Uranium and uranium-plutonium metallic alloy with predominantly stainless-steel cladding
15.	Naval fuel	Surface ship/ submarine	Uranium-based with zirconium alloy cladding
16.	Miscellaneous	Not specified	Various fuel compounds with or without zirconium alloy, aluminum, Hastelloy, tantalum, niobium, stainless-steel or unknown cladding

a. Source: DIRS 104385-Fillmore (1998, all).

b. Abbreviations: SNF = spent nuclear fuel; HWCTR = heavy-water cooled test reactor; PWR = pressurized-water reactor; TMI = Three Mile Island; ATR = Advanced Test Reactor; FRR MTR = foreign research reactor – material test reactor; FFTF = Fast Flux Test Facility; LWBR = light-water breeder reactor; TRIGA = Training Research Isotopes—General Atomic; EBR-II = Experimental Breeder Reactor II.

c. For ongoing repository performance analyses, the 16 DOE fuel categories have been reduced to 11 categories (DIRS 118968-DOE 2000, all) since the publication of the Draft EIS. The reduction reflects a better understanding of the behavior of DOE fuels under repository conditions and allows the combining of some of the 16 DOE fuel categories. The reduced DOE fuel categories will help streamline future repository analyses of DOE fuels.

A.2.2.3 Present Storage and Generation Status

Table A-20 lists storage locations and inventory information on DOE spent nuclear fuels. During the preparation of the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DIRS 101802-DOE 1995, all), DOE evaluated and categorized

Table A-20. National Spent Nuclear Fuel Database projection of DOE spent nuclear fuel locations and inventories to 2035.[a,b]

Fuel category and name	Storage Site	No. of units[c]	Mass (kilograms)[d]	Volume (cubic meters)[e]	Fissile mass (kilograms)	Equivalent uranium mass (kilograms)	MTHM
1. Uranium metal[f]	INEEL	85	4,500	0.7	13	1,700	1.7
	Hanford	100,000	2,160,000	200	25,000	2,100,000	2100
	SRS	350	120,000	18	110	17,000	17
	Totals	*100,435*	*2,284,500*	*218.7*	*25,123*	*2,118,700*	*2119*
2. Uranium-zirconium	INEEL	69	120	0.7	34	40	0.04
3. Uranium-molybdenum	INEEL	29,000	4,600	0.3	970	3,800	3.8
4. Uranium oxide, intact	INEEL	14,000	150,000	41	2,200	80,000	80
	Hanford	87	44,000	11	240	18,000	18
	Totals	*14,087*	*194,000*	*52*	*2,440*	*98,000*	*99*
5. Uranium oxide, failed/declad/aluminum clad	INEEL	2,000	340,000	140	2,200	83,000	84
	Hanford	13	270	4.2	4	160	0.2
	SRS	7,600	58,000	96	2,600	3,200	3.2
	Totals	*9,613*	*398,270*	*240.2*	*4,804*	*86,360*	*87*
6. Uranium-aluminide	SRS	18,000	130,000	150	6,000	8,800	8.7
7. Uranium-silicide	SRS	7,400	47,000	53	1,200	12,000	12
8. Thorium/uranium carbide, high-integrity	FSV	1,500	190,000	130	640	820	15
	INEEL	1,600	130,000	82	350	440	9.9
	Totals	*3,100*	*320,000*	*212*	*990*	*1,260*	*25*
9. Thorium/uranium carbide, low-integrity	INEEL	810	55,000	17	180	210	1.7
10. Plutonium/uranium carbide, nongraphite	INEEL	130	140	0	10	73	0.08
	Hanford	2	330	0.1	11	64	0.07
	Totals	*132*	*470*	*0.1*	*21*	*137*	*0.2*
11. Mixed oxide	INEEL	2,000	6,100	2.4	240	2,000	2.1
	Hanford	620	110,000	33	2,400	8,000	10
	Totals	*2,620*	*116,100*	*35.1*	*2,640*	*10,000*	*12*
12. Uranium/thorium oxide	INEEL	260	120,000	18	810	810	50
13. Uranium-zirconium hydride	INEEL	9,800	33,000	8.1	460	2,000	2
	Hanford	190	660	33	7	36	0.04
	Totals	*9,990*	*33,660*	*8.3*	*467*	*2,036*	*2*
15. Naval fuel[g]	INEEL	300	4,400,000	888	64,000	65,000	65
16. Miscellaneous	INEEL	1,500	33,000	11	360	5,500	7.7
	Hanford	73	1,700	0.2	30	130	0.2
	SRS	8,800	9,200	8.2	550	2,900	2.9
	Totals	*10,373*	*43,900*	*19.4*	*940*	*8,530*	*11*
Grand totals		***210,000***	***8,150,000***	***1,900***	***110,000***	***2,420,000***	***2,500***

a. Source: DIRS 148240-Dirkmaat (1998, all).
b. Abbreviations: SNF = spent nuclear fuel; INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; FSV = Fort St. Vrain.
c. Unit is defined as an assembly, bundle of elements, can of material, etc., depending on the particular spent nuclear fuel category.
d. To convert kilograms to pounds, multiply by 2.2046; to convert metric tons to tons, multiply by 1.1023.
e. To convert cubic meters to cubic yards, multiply by 1.3079.
f. N-Reactor fuel is stored in aluminum or stainless-steel cans at the K-East and K-West Basins. The mass listed in this table does not include the storage cans.
g. Information supplied by the Navy (DIRS 104356-Dirkmaat 1997, Attachment, p. 2).

all the materials listed in the table as spent nuclear fuel, in accordance with the definition in the Nuclear Waste Policy Act, as amended.

A.2.2.4 Final Spent Nuclear Fuel Form

For all spent nuclear fuel categories except 14, the expected final spent nuclear fuel form does not differ from the current or planned storage form. Before its disposal in the repository, candidate material would be in compliance with approved acceptance criteria.

DOE has prepared an EIS at the Savannah River Site (DIRS 156897-DOE 2000, all) to evaluate potential treatment alternatives for spent nuclear fuel and its ultimate disposal in the repository. The products of any proposed treatment of the Savannah River Site aluminum-based fuels are adequately represented by the properties of the present aluminum-based fuel (Categories 6, 7, and part of 5) for this Yucca Mountain EIS. They are bounded by the same total radionuclide inventory, heat generation rates, dissolution rates, and number of canisters. No additional data about the products will be required to ensure that they are represented in the EIS inventory.

A.2.2.5 Spent Nuclear Fuel Characteristics

A.2.2.5.1 *Mass and Volume*

Table A-20 lists total volume, mass, and MTHM for each DOE spent nuclear fuel category from the National Spent Nuclear Fuel Database (DIRS 153072-Wheatley 2000, all).

A.2.2.5.2 *Amount and Nature of Radioactivity*

ORIGEN2 (Oak Ridge Isotope Generation), an accepted computer code for calculating spent nuclear fuel radionuclide inventories, was used to generate activity data for radionuclides in the DOE spent nuclear fuel inventory. The inventory came from the 1997 version of the National Spent Nuclear Fuel Database (DIRS 153072-Wheatley 2000, all).

Table A-21 lists the activities expressed in terms of curies per handling unit for the radionuclides of interest (uranium, fission products and actinides). The table lists activity estimates decayed to 2030 for all categories except 15. A handling unit for DOE is a spent nuclear fuel canister. The canister quantities (except the naval fuel) are estimated based on the fuel's current as-stored condition at each of the DOE facilities. The planned storage, transportation, and disposal unit for naval spent nuclear fuel is a canister. Each naval spent nuclear fuel canister would contain several spent fuel assemblies. The actual canister quantities for repository disposition could be different depending on final package configuration and whether the fuels were treated as discussed in Section A.1.1.3.

The activity for naval spent nuclear fuel (Category 15) is provided for a representative naval canister. DIRS 104356-Dirkmaat (1997, Attachment A, Table 3) provided these activities for 5 years after shutdown, which would be the minimum cooling time before naval fuel would reach the repository. The power history assumed operations at power for a full core life. The assumptions about the power history and minimum cooling time conservatively bound the activity for naval fuel that would be emplaced in a monitored geologic repository. In addition, ORIGEN-S was used to calculate the activity associated with activation products in the cladding, which are listed in Table A-21. For completeness, the data also include the activity that would be present in the activated corrosion products deposited on the fuel.

A.2.2.5.3 *Chemical Composition*

This section discusses the chemical compositions of each of the 16 categories of DOE spent nuclear fuel (DIRS 148240-Dirkmaat 1998, all).

- *Category 1: Uranium metal.* The fuel in this category consists primarily of uranium metal. N-reactor fuel represents the category because its mass is so large that the performance of the rest of the fuel in the category, even if greatly different from N-Reactor fuel, would not change the overall category performance. The fuel is composed of uranium metal about 1.25 percent enriched in uranium-235, and is clad with a zirconium alloy. Approximately 50 percent of the fuel elements are believed to have failed cladding. This fuel typically has low burnup. Another contributor to this category is the Single Pass Reactor fuel at the Hanford Site.

Table A-21. Radionuclide activity by DOE spent nuclear fuel category[a] (page 1 of 2).

Storage site[b]	Category[c] 1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
	Number of handling units														
Hanford	440	0	0	34	1	0	0	0	0	2	324	0	3	0	5
INEEL	6	8	70	195	406	0	0	503[d]	60	3	43	71	97	300	39
SRS	9	0	0	0	425	750	225	0	0	0	0	0	0	0	2
Totals	***455***	***8***	***70***	***229***	***832***	***750***	***225***	***503***	***60***	***5***	***367***	***71***	***100***	***300***	***46***
Radio-nuclide[g]	Curies per handling unit														
Ac-227	2.2×10^{-5}	4.8×10^{-9}	6.9×10^{-6}	1.7×10^{-4}	1.4×10^{-5}	3.4×10^{-7}	2.3×10^{-7}	0	2.8×10^{-3}	8.9×10^{-9}	1.5×10^{-9}	4.3×10^{-1}	5.6×10^{-8}	9.8×10^{-5}	6.8×10^{-7}
Am-241	1.1×10^{3}	3.9×10^{-1}	4.6×10^{-5}	1.6×10^{3}	7.3	3.3	3.6×10^{1}	3.7	2.7	2.4×10^{2}	4.3×10^{2}	8.3×10^{-1}	2.0×10^{-1}	5.0×10^{1}	1.2×10^{2}
Am-242m	6.6×10^{-2}	1.2×10^{-3}	0	2.6	1.4×10^{-2}	2.3×10^{-3}	1.3×10^{-2}	1.0×10^{-3}	1.4×10^{-3}	4.1×10^{-1}	7.5×10^{-1}	8.7×10^{-3}	2.3×10^{-3}	4.6×10^{-1}	1.5×10^{-1}
Am-243	2.8×10^{-1}	3.8×10^{-3}	7.3×10^{-13}	8.3	2.2×10^{-2}	2.5×10^{-3}	3.6×10^{-2}	2.7×10^{-2}	1.3×10^{-3}	6.7×10^{-3}	1.8×10^{-1}	1.7×10^{-3}	2.5×10^{-4}	6.7×10^{-1}	4.9×10^{-1}
C-14	1.5	8.2×10^{-6}	2.2×10^{-3}	1.0×10^{-1}	1.1×10^{-3}	9.9×10^{-7}	1.8×10^{-5}	2.2×10^{-1}	3.7×10^{-2}	1.5×10^{-5}	9.9×10^{-4}	6.7×10^{-1}	8.5×10^{-2}	1.6×10^{1}	1.7×10^{-3}
Cf-252	--[e]	--	--	--	--	--	--	--	--	--	--	--	--	1.2×10^{-6}	--
Cl-36	0	0	5.6×10^{-6}	3.5×10^{-4}	1.7×10^{-5}	0	0	2.7×10^{-3}	1.1×10^{-3}	0	1.1×10^{-5}	1.5×10^{-2}	2.6×10^{-3}	6.9×10^{-1}	4.2×10^{-6}
Cm-242	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	0	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.4\times10^{1}$	$< 7.3\times10^{1}$	$< 7.4\times10^{1}$	1.4	$< 7.4\times10^{1}$
Cm-243	--	--	--	--	--	--	--	--	--	--	--	--	--	7.9×10^{-1}	
Cm-244	8.5	1.6×10^{-1}	6.8×10^{-14}	3.5×10^{2}	9.3×10^{-1}	2.1×10^{-2}	3.0×10^{-1}	8.3×10^{-1}	3.5×10^{-2}	2.8×10^{-1}	7.6	1.6×10^{-1}	6.8×10^{-3}	6.3×10^{1}	1.9×10^{1}
Cm-245	3.6×10^{-3}	8.0×10^{-6}	1.9×10^{-19}	1.4×10^{-1}	3.8×10^{-4}	1.8×10^{-6}	2.0×10^{-5}	1.4×10^{-4}	4.0×10^{-6}	1.4×10^{-5}	3.1×10^{-3}	3.3×10^{-5}	1.4×10^{-7}	7.2×10^{-3}	7.1×10^{-3}
Cm-246	5.3×10^{-4}	5.5×10^{-7}	6.1×10^{-23}	2.4×10^{-2}	6.4×10^{-5}	8.6×10^{-8}	1.5×10^{-6}	6.9×10^{-5}	1.3×10^{-7}	9.7×10^{-7}	5.3×10^{-4}	2.2×10^{-6}	3.9×10^{-9}	1.4×10^{-3}	1.2×10^{-3}
Cm-247	--	--	--	--	--	--	--	--	--	--	--	--	--	9.4×10^{-9}	--
Cm-248	--	--	--	--	--	--	--	--	--	--	--	--	--	2.6×10^{-8}	--
Co-60	1.4×10^{-1}	0	1.1×10^{-2}	1.8×10^{1}	1.6×10^{-12}	1.2×10^{-11}	2.0×10^{-10}	0	2.5×10^{-2}	1.8	1.4	4.3	1.8×10^{-1}	3.7×10^{3}(f)	7.6×10^{-4}
Cs-134	2.7×10^{-1}	4.6×10^{-2}	1.9×10^{-8}	9.6×10^{-2}	8.3×10^{-3}	1.7×10^{-1}	3.7×10^{-1}	7.6×10^{-3}	3.6×10^{-7}	3.4×10^{-2}	7.5×10^{-3}	6.0×10^{-3}	3.3×10^{-4}	8.4×10^{4}	5.7×10^{-1}
Cs-135	1.8×10^{-1}	7.7×10^{-3}	4.5×10^{-3}	1.8×10^{-1}	2.9×10^{-2}	2.8×10^{-2}	1.9×10^{-2}	1.7×10^{-2}	2.6×10^{-2}	1.4×10^{-2}	3.2×10^{-3}	2.0×10^{-1}	3.2×10^{-2}	4.6	1.4×10^{-1}
Cs-137	2.0×10^{4}	7.4×10^{3}	0	2.9×10^{4}	3.6×10^{3}	3.8×10^{3}	8.1×10^{3}	2.4×10^{3}	1.9×10^{3}	1.5×10^{4}	4.0×10^{3}	2.5×10^{3}	3.1×10^{3}	4.5×10^{5}	8.7×10^{4}
H-3	2.3×10^{1}	4.4	8.6×10^{-2}	3.6×10^{1}	1.3	5.9×10^{-1}	1.3×10^{1}	2.0	1.5	7.3	2.8	2.3×10^{1}	9.6×10^{-1}	1.4×10^{3}	1.3×10^{1}
I-129	1.6×10^{-2}	1.6×10^{-3}	1.2×10^{-4}	1.8×10^{-2}	7.5×10^{-4}	1.8×10^{-3}	3.8×10^{-3}	2.1×10^{-3}	7.3×10^{-4}	2.9×10^{-3}	3.6×10^{-4}	1.1×10^{-2}	7.2×10^{-4}	1.2×10^{-1}	2.3×10^{-2}
Kr-85	3.6×10^{2}	9.3×10^{1}	7.7×10^{-1}	3.1×10^{2}	2.7×10^{1}	1.3×10^{2}	2.6×10^{2}	6.0×10^{1}	7.2	4.8×10^{1}	2.4×10^{1}	6.2×10^{2}	1.7×10^{1}	3.6×10^{4}	4.2×10^{2}
Nb-93m	8.0×10^{-1}	8.7×10^{-3}	4.6×10^{-3}	6.7×10^{-1}	1.1×10^{-2}	1.6×10^{-2}	3.1×10^{-2}	9.2×10^{-3}	4.6×10^{-2}	1.5×10^{-2}	1.3×10^{-2}	3.1×10^{-1}	7.1×10^{-3}	3.6	1.7×10^{-1}
Nb-94	5.7×10^{-6}	1.6×10^{-6}	8.4×10^{-4}	7.3×10^{-3}	4.2×10^{-5}	3.1×10^{-6}	7.4×10^{-6}	1.3×10^{-4}	4.9×10^{-4}	2.9×10^{-6}	1.9×10^{-5}	1.6×10^{-2}	4.6×10^{-3}	1.8×10^{2}	3.5×10^{-5}
Ni-59	8.2×10^{-2}	0	6.9×10^{-3}	9.4×10^{-2}	2.3×10^{-4}	0	0	1.7×10^{-2}	1.5×10^{-3}	0	2.1×10^{-3}	5.1×10^{-2}	5.0×10^{-1}	6.3×10^{1}	8.2×10^{-4}
Ni-63	7.7	0	1.4×10^{-1}	3.0×10^{2}	2.5×10^{-2}	2.3×10^{-22}	0	4.1×10^{-1}	1.5×10^{-1}	5.0	8.7	6.2	6.2×10^{1}	7.8×10^{3}	1.0×10^{-1}
Np-237	1.7×10^{-1}	2.0×10^{-2}	3.3×10^{-4}	1.8×10^{-1}	3.1×10^{-3}	1.2×10^{-2}	1.8×10^{-2}	1.6×10^{-2}	7.4×10^{-3}	3.7×10^{-2}	6.5×10^{-3}	7.1×10^{-4}	1.9×10^{-3}	1.6	2.4×10^{-1}
Pa-231	5.8×10^{-5}	2.3×10^{-7}	2.0×10^{-5}	3.0×10^{-4}	2.6×10^{-5}	4.2×10^{-6}	2.8×10^{-6}	1.9×10^{-2}	4.8×10^{-3}	4.1×10^{-7}	1.2×10^{-7}	1.1	9.0×10^{-7}	5.2×10^{-4}	1.0×10^{-5}
Pb-210	3.2×10^{-10}	8.6×10^{-13}	1.4×10^{-10}	9.0×10^{-8}	5.2×10^{-9}	2.1×10^{-11}	1.2×10^{-11}	4.6×10^{-6}	2.6×10^{-7}	1.5×10^{-12}	3.1×10^{-10}	7.8×10^{-5}	1.4×10^{-12}	8.9×10^{-7}	7.510^{-10}

Table A-21. Radionuclide activity by DOE spent nuclear fuel category[a] (page 2 of 2).

Radio-nuclide[g]	Category[b]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
	Curies per handling unit														
Pd-107	3.3×10^{-2}	1.1×10^{-3}	1.3×10^{-4}	4.8×10^{-2}	8.3×10^{-4}	9.3×10^{-4}	3.5×10^{-3}	8.7×10^{-4}	4.8×10^{-4}	2.0×10^{-3}	1.0×10^{-3}	2.4×10^{-3}	6.0×10^{-4}	6.0×10^{-2}	1.8×10^{-2}
Pu-238	2.5×10^{2}	4.3×10^{1}	1.7×10^{-2}	1.2×10^{3}	5.8	1.7×10^{1}	2.8×10^{1}	8.1×10^{1}	1.8×10^{1}	1.1×10^{2}	7.9×10^{1}	2.8	2.1	1.2×10^{4}	5.3×10^{2}
Pu-239	5.1×10^{2}	1.1	2.0	1.5×10^{2}	1.3×10^{1}	2.4	2.2×10^{1}	2.3×10^{-1}	4.1×10^{-1}	1.9×10^{2}	3.2×10^{2}	1.8×10^{-1}	4.5	1.2×10^{1}	5.2×10^{1}
Pu-240	3.0×10^{2}	6.1×10^{-1}	6.1×10^{-3}	2.4×10^{2}	4.4	1.2	1.6×10^{1}	3.8×10^{-1}	3.2×10^{-1}	1.6×10^{2}	2.8×10^{2}	1.0×10-1	1.8	1.4×10^{1}	3.7×10^{1}
Pu-241	3.8×10^{3}	2.1×10^{2}	6.0×10^{-4}	1.4×10^{4}	2.9×10^{2}	6.3×10^{1}	7.0×10^{2}	0	3.0×10^{1}	1.7×10^{3}	2.6×10^{3}	2.4×10^{1}	1.3×10^{2}	4.0×10^{3}	3.5×10^{3}
Pu-242	1.6×10^{-1}	9.2×10^{-4}	3.8×10^{-11}	9.1×10^{-1}	3.0×10^{-3}	9.9×10^{-4}	1.6×10^{-2}	0	4.2×10^{-4}	1.6×10^{-3}	2.0×10^{-2}	2.3×10^{-4}	2.5×10^{-4}	8.0×10^{-2}	7.0×10^{-2}
Ra-226	4.6×10^{-6}	2.2×10^{-12}	6.5×10^{-10}	2.6×10^{-7}	2.0×10^{-8}	3.8×10^{-10}	2.3×10^{-10}	4.9×10^{-6}	9.3×10^{-7}	2.3×10^{-9}	5.3×10^{-9}	4.5×10^{-5}	2.3×10^{-12}	5.4×10^{-6}	4.1×10^{-9}
Ra-228	3.7×10^{-10}	1.2×10^{-13}	4.0×10^{-9}	1.3×10^{-4}	1.1×10^{-5}	7.3×10^{-13}	1.1×10^{-12}	6.5×10^{-3}	2.4×10^{-3}	6.9×10^{-13}	2.0×10^{-11}	7.1×10^{-2}	3.5×10^{-9}	1.8×10^{-7}	1.5×10^{-11}
Rh-102	--	--	--	--	--	--	--	--	--	--	--	--	--	2.8×10^{-2}	--
Ru-106	3.1×10^{-5}	6.3×10^{-7}	3.1×10^{-15}	3.9×10^{-7}	1.2×10^{-6}	1.3×10^{-5}	4.2×10^{-5}	3.2×10^{-9}	3.0×10^{-15}	2.6×10^{-6}	3.1×10^{-8}	2.2×10^{-10}	1.5×10^{-9}	6.0×10^{3}	5.7×10^{-5}
Se-79	2.6×10^{-1}	3.0×10^{-2}	1.7×10^{-3}	1.9×10^{-1}	1.6×10^{-2}	5.0×10^{-2}	1.0×10^{-1}	2.9×10^{-2}	1.4×10^{-2}	5.2×10^{-2}	3.6×10^{-3}	2.5×10^{-1}	1.3×10^{-2}	3.4×10^{-1}	4.7×10^{-1}
Sm-151	3.3×10^{2}	2.7×10^{1}	6.9	5.3×10^{2}	2.5×10^{1}	4.2×10^{1}	3.4×10^{1}	4.5×10^{1}	2.6×10^{1}	1.8×10^{2}	2.4×10^{2}	9.1×10^{1}	2.4×10^{1}	1.4×10^{3}	3.8×10^{2}
Sn-126	3.5×10^{-1}	2.6×10^{-2}	3.8×10^{-3}	2.4×10^{-1}	1.2×10^{-2}	1.7×10^{-2}	4.1×10^{-2}	1.4×10^{-2}	1.2×10^{-2}	4.7×10^{-2}	4.8×10^{-3}	2.8×10^{-1}	1.2×10^{-2}	1.2	3.3×10^{-1}
Sr-90	1.6×10^{4}	7.1×10^{3}	0	2.1×10^{4}	3.2×10^{3}	3.7×10^{3}	7.6×10^{3}	2.3×10^{3}	1.8×10^{3}	1.3×10^{4}	1.6×10^{3}	2.6×10^{3}	2.9×10^{3}	4.4×10^{5}	8.3×10^{4}
Tc-99	7.7	9.9×10^{-1}	4.5×10^{-2}	6.6	4.2×10^{-1}	1.0	2.2	7.4×10^{-1}	4.1×10^{-1}	1.8	1.3×10^{-1}	2.3	4.3×10^{-1}	7.0×10^{1}	1.4×10^{1}
Th-229	3.9×10^{-8}	1.1×10^{-10}	2.4×10^{-9}	4.0×10^{-4}	3.2×10^{-5}	2.2×10^{-9}	1.2×10^{-9}	2.8×10^{-2}	6.8×10^{-3}	2.5×10^{-10}	1.7×10^{-9}	1.8×10^{-1}	1.2×10^{-9}	9.4×10^{-6}	8.7×10^{-9}
Th-230	4.4×10^{-6}	8.6×10^{-9}	1.2×10^{-7}	3.7×10^{-5}	2.9×10^{-6}	1.8×10^{-7}	1.2×10^{-7}	1.9×10^{-3}	1.3×10^{-4}	5.1×10^{-7}	1.2×10^{-6}	6.9×10^{-3}	3.9×10^{-9}	1.8×10^{-3}	1.2×10^{-6}
Th-232	5.1×10^{-10}	2.0×10^{-12}	4.3×10^{-9}	1.4×10^{-4}	1.2×10^{-5}	1.9×10^{-11}	3.0×10^{-11}	5.1×10^{-3}	2.5×10^{-3}	4.4×10^{-12}	5.5×10^{-11}	8.4×10^{-2}	1.0×10^{-8}	2.3×10^{-7}	9.8×10^{-11}
U-232	9.9×10^{-5}	3.5×10^{-5}	1.9×10^{-6}	0	2.2×10^{-5}	1.7×10^{-4}	1.4×10^{-4}	2.3	2.4×10^{-1}	0	0	7.1×10^{2}	2.4×10^{-5}	5.6×10^{-1}	3.5×10^{-4}
U-233	2.5×10^{-5}	9.1×10^{-7}	9.9×10^{-7}	1.6×10^{-1}	1.2×10^{-2}	2.6×10^{-6}	1.8×10^{-6}	6.9	2.6	1.7×10^{-6}	9.3×10^{-7}	1.2×10^{2}	5.6×10^{-6}	3.1×10^{-3}	1.6×10^{-5}
U-234	2.0	8.6×10^{-4}	5.0×10^{-4}	1.7×10^{-1}	1.1×10^{-2}	2.2×10^{-3}	1.8×10^{-3}	5.6×10^{-1}	4.4×10^{-1}	4.9×10^{-3}	8.0×10^{-3}	5.9	2.1×10^{-4}	1.5×10^{1}	1.8×10^{-2}
U-235	8.4×10^{-2}	8.2×10^{-3}	3.2×10^{-2}	1.7×10^{-2}	1.2×10^{-2}	1.8×10^{-2}	1.3×10^{-2}	2.2×10^{-3}	6.8×10^{-3}	1.5×10^{-2}	2.2×10^{-4}	4.0×10^{-4}	9.9×10^{-3}	2.9×10^{-1}	1.2×10^{-1}
U-236	3.3×10^{-1}	3.4×10^{-2}	1.7	1.4×10^{-1}	1.2×10^{-2}	3.7×10^{-2}	5.9×10^{-2}	2.1×10^{-2}	1.7×10^{-2}	6.0×10^{-2}	4.1×10^{-3}	8.1×10^{-4}	1.3×10^{-2}	2.5	4.4×10^{-1}
U-238	1.6	1.5×10^{-4}	1.4×10^{-2}	1.3×10^{-1}	3.4×10^{-2}	8.9×10^{-4}	1.6×10^{-2}	5.4×10^{-5}	7.1×10^{-5}	2.7×10^{-4}	2.7×10^{-3}	1.3×10^{-5}	5.8×10^{-3}	1.2×10^{-3}	2.4×10^{-2}
Zr-93	1.0	1.5×10^{-1}	6.7×10^{-3}	9.1×10^{-1}	5.0×10^{-2}	1.0×10^{-1}	2.1×10^{-1}	1.1	6.4×10^{-2}	2.7×10^{-1}	1.7×10^{-2}	5.7×10^{-1}	7.8×10^{-2}	1.1×10^{1}	1.9

a. Source: DIRS 148240-Dirkmaat (1998, all); DIRS 155857-McKenzie (2001, Attachment B, p. 9). Values are rounded to two significant figures.
b. INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site.
c. Categories 1-13 and 16 decayed to 2030. Category 15 cooled for 5 years.
d. Includes 334 canisters from Fort St. Vrain.
e. -- = not found in appreciable quantities.
f. Amount of cobalt-60 as crud is 5.8 curies.
g. Half-lives are listed in Table A-11, with the exception of Cf-252 = 2.65 years, Cm-242 = 1.6×10^{7} years, Cm-248 = 3.4×10^{5} years, Rh-102 = 2.9 years, Th-229 = 7.9×10^{3} years, and Th-232 = 1.4×10^{10} years.

- *Category 2: Uranium-zirconium.* The fuel in this category consists primarily of a uranium- (91 percent) zirconium alloy. The Heavy Water Components Test Reactor fuel is the representative fuel because it is the largest part of the inventory. This fuel is approximately 85-percent enriched in uranium-235 and is clad with a zirconium alloy.

- *Category 3: Uranium molybdenum.* The fuel in this category consists of uranium- (10 percent)-molybdenum alloy and 25-percent enriched in uranium-235, and is clad with a zirconium alloy. Fermi driver core 1 and 2 are the only fuels in the category. The fuel is currently in an aluminum container. The proposed disposition would include the aluminum container.

- *Category 4: Uranium oxide, intact.* The fuel in this category consists of uranium oxide that has been formed into pellets or plates and clad with a corrosion-resistant material. Commercial fuel is the representative fuel for this category because it is a large part of the inventory. The fuel is made of uranium oxide, some of which is highly enriched in uranium-235 and some of which is low enriched in uranium-235. The fuel elements are clad with a zirconium alloy.

- *Category 5: Uranium oxide, failed/declad/aluminum clad.* The fuel in this category is chemically similar to the fuels in Category 4, except accident or destructive examination has disrupted it. The failed fuel from Three Mile Island Reactor 2 represents this category because it comprises 96 percent of the total MTHM of the category. The Three Mile Island Reactor 2 fuel is melted uranium oxide. The accident greatly disrupted the cladding. Other fuel in this category is declad or has a large amount of cladding damage. Approximately 4 percent consists of intact aluminum clad fuel included in this category because the aluminum cladding is less corrosion resistant than Category 4 cladding material.

- *Category 6: Uranium-aluminide.* This category consists of fuel with a uranium-aluminum compound dispersed in a continuous aluminum metal phase. The fuel is clad with an aluminum alloy. The uranium-235 enrichment varies from 10 to 93 percent.

- *Category 7: Uranium-silicide.* The fuel in this category is a uranium-silicide compound dispersed in a continuous aluminum metal phase. The fuel is clad with an aluminum alloy. The uranium-235 enrichment varies from 8 to 93 percent, but most are less than 20 percent.

- *Category 8: Thorium/uranium carbide, high-integrity.* This category consists of fuels with thorium carbide or uranium carbide formed into particles with a high-integrity coating. Fort St. Vrain Reactor fuel represents the category because it makes up 95 percent of the mass of the category. This fuel is uranium carbide and thorium carbide formed into particles and coated with layers of pyrolytic carbon and silicon carbide. The particles are bonded in a carbonaceous matrix material and emplaced in a graphite block. The fuel was made with uranium enriched to 93 percent in uranium-235. The thorium was used to generate fissile uranium-233 during irradiation. Some fuel does not have a silicon carbide coating, but its effect on the category is very small. Less than 1 percent of the fuel particles are breached.

- *Category 9: Thorium/uranium carbide, low-integrity.* This category consists of fuels with uranium carbide or thorium carbide made into particles with a coating of an earlier design than that described for Category 8. Peach Bottom Unit 1, Core 1 is the only fuel in this category. This fuel is chemically similar to Category 8 fuel except 60 percent of the particle coating is breached. Peach Bottom Unit 1, Core 2 is included in Category 8 because its fuel particles are basically intact and are more rugged than the Peach Bottom Unit 1, Core 1 particles.

- *Category 10: Plutonium/uranium carbide, nongraphite.* This category consists of fuel that contains uranium carbide. Much of it also contains plutonium carbide. Fast Flux Test Facility carbide assemblies represent this category because they make up 70 percent of the category and contain both uranium and plutonium. The Fast Flux Test Facility carbide fuel was constructed from uncoated uranium and plutonium carbide spheres that were loaded directly into the fuel pins, or pressed into pellets that were loaded into the pins. The pins are clad with stainless steel.

- *Category 11: Mixed oxide.* This category consists of fuels constructed of both uranium oxide and plutonium oxide. The Fast Flux Test Facility mixed-oxide test assembly is the representative fuel because it comprises more than 80 percent of the category. The fuels are a combination of uranium oxide and plutonium oxide pressed into pellets and clad with stainless steel or a zirconium alloy. The uranium-235 enrichment is low, but the fissile contribution of the plutonium raises the effective enrichment to 15 percent.

- *Category 12: Uranium/thorium oxide.* This category consists of fuels constructed of uranium oxide and thorium oxide. Shippingport light-water breeder reactor fuel is the representative fuel because it comprises more than 75 percent of the inventory. The Shippingport light-water breeder reactor fuel is made of uranium-233, and the irradiation of the thorium produces more uranium-233. The mixture is pressed into pellets and clad with a zirconium alloy.

- *Category 13: Uranium-zirconium hydride.* This category consists of fuels made of uranium-zirconium hydride. Training Research Isotopes-General Atomic fuels comprise more than 90 percent of the mass of this category. The fuel is made of uranium-zirconium hydride formed into rods and clad primarily with stainless steel or aluminum. The uranium is enriched as high as 90 percent in uranium-235, but most is less than 20 percent enriched.

- *Category 14: Sodium-bonded.* For purposes of analysis in this EIS, it is assumed that all Category 14 fuels would be treated during the proposed electrometallurgical treatment that would result in high-level radioactive waste. The chemical composition of the resulting high-level radioactive waste is described in Section A.2.3.5.3. Category 14 is included here for completeness.

- *Category 15: Naval fuel.* Naval nuclear fuel is highly robust and designed to operate in a high-temperature, high-pressure environment for many years. This fuel is highly enriched (93 to 97 percent) in uranium-235. In addition, to ensure that the design will be capable of withstanding battle shock loads, the naval fuel material is surrounded by large amounts of zirconium alloy (DIRS 124679-Beckett 1998, Attachment 2).

  DOE plans to emplace approximately 300 canisters of naval spent nuclear fuel in the Yucca Mountain Repository. There are several different designs for naval nuclear fuel, but all designs employ similar materials and mechanical arrangements. The total weight of typical fuel assemblies in a canister would be 11,000 to 13,000 kilograms (24,000 to 29,000 pounds). Of this total, less than 500 kilograms (1,100 pounds) would be uranium. Approximately 1,000 to 2,000 kilograms (2,200 to 4,400 pounds) of the total weight of these fuel assemblies is from hafnium in the poison devices (primarily control rods) permanently affixed to the fuel assemblies (DIRS 124679-Beckett 1998, Attachment 2).

  There would be approximately 9,000 to 12,000 kilograms (20,000 to 26,500 pounds) of zirconium alloy in the fuel structure in the typical canister. The typical chemical composition of zirconium alloy is approximately 98 percent zirconium, 1.5 percent tin, 0.2 percent iron, and 0.1 percent chromium (DIRS 124679-Beckett 1998, Attachment 2).

The small remainder of the fuel mass in a typical canister of naval spent nuclear fuel [less than 500 kilograms (1,100 pounds)] would consist of small amounts of such metals and nonmetals as fission products and oxides (DIRS 124679-Beckett 1998, Attachment 2).

- *Category 16: Miscellaneous.* This category consists of the fuels that do not fit into the previous 15 categories. The largest amount of this fuel, as measured in MTHM, is uranium metal or alloy. The other two primary contributors are uranium alloy and uranium-thorium alloy. These three fuel types make up more than 80 percent of the MTHM in the category. It is conservative to treat the total category as uranium metal. Other chemical compounds included in this category include uranium oxide, uranium nitride, uranium alloys, plutonium oxide, plutonium nitride, plutonium alloys, and thorium oxide.

Table A-22 lists the primary materials of construction and chemical composition for each category.

A.2.2.5.4 *Thermal Output*

Table A-23 lists the maximum heat generation per handling unit for each spent nuclear fuel category (DIRS 104354-Dirkmaat 1997, Attachment, pp. 74 to 77; DIRS 104377-Dirkmaat 1998, all). The category 15 (naval fuel) thermal data used the best estimate radionuclide content from DIRS 104354-Dirkmaat (1997, Attachment, pp. 74 to 77) at a minimum cooling time of 5 years.

A.2.2.5.5 *Quantity of Spent Nuclear Fuel Per Canister*

Table A-24 lists the projected number of canisters required for each site and category. The amount of fuel per canister would vary widely among categories and would depend on a variety of parameters. The average mass of naval spent nuclear fuel in a short naval canister would be approximately 13 metric tons (14 tons) with an associated volume of 2.7 cubic meters (95 cubic feet). Naval spent nuclear fuel in a long naval canister would have an average mass of approximately 18 metric tons (20 tons) and a volume of 3.5 cubic meters (124 cubic feet) (DIRS 104354-Dirkmaat 1997, Attachment, p. 108).

A.2.2.5.6 *Spent Nuclear Fuel Canister Parameters*

The Idaho National Engineering and Environmental Laboratory would use a combination of 46- and 61-centimeter (18- and 24-inch)-diameter stainless-steel canisters for spent nuclear fuel disposition. The Savannah River Site would use 18-inch canisters, and Hanford would use 64-centimeter (25.3-inch) multicanister overpacks and 18-inch canisters. Table A-24 lists the specific number of canisters per site. Detailed canister design specifications for the standard 18- and 24-inch canisters are contained in DIRS 137713-DOE (1998, all). Specifications for the Hanford multicanister overpacks are in DIRS 103499-Parsons (1999, all).

There are two conceptual canister designs for naval fuel: one with a length of 539 centimeters (212 inches) and one with a length of 475 centimeters (187 inches). Both canisters would have a maximum diameter of 169 centimeters (67 inches) (DIRS 104354-Dirkmaat 1997, Attachment, pp. 86 to 88). Table A-25 summarizes the preliminary design information.

For both designs, the shield plug, shear ring, and outer seal plate would be welded to the canister shell after the fuel baskets were loaded in the canister. The shield plug, shear ring, and welds, along with the canister shell and bottom plug, would form the containment boundary for the disposable container. The shell, inner cover, and outer cover material for the two canisters would be low-carbon austenitic stainless steel or stabilized austenitic stainless steel. Shield plug material for either canister would be stainless steel (DIRS 104354-Dirkmaat 1997, Attachment, pp. 86 to 88).

Table A-22. Chemical composition of DOE spent nuclear fuel by category (kilograms).[a,b]

Fuel	Category 1	2	3	4	5	6	7	8	9	10	11	12	13	15	16
Components															
Uranium	2,120,000	40	3,800	98,000	87,000	8,800	12,000	1,300	210	140	9,900	810	2,000	65,000	8,500
Aluminum	1,700	(c)				18,000	4,200								
Molybdenum			380										9		
Zirconium	140	440		7,500									23,000		
Thorium								27,000	1,500			48,000			2,200
Plutonium										16	2,400				8
Silicon	260						880								
Silicon carbide								53,000							
Carbon	1,200			30				220,000	53,000				1,700		
Cladding and structure															
Aluminum	100		640		18,000	64,000	52,000						11,000		500
Stainless steel				11,000	3,000				8,000	320	2,400	31,000	17,000		20,000
Zirconium alloy	160,000	70	280	64,000	58,000						500	12,000	100	3,600,000	100
Inconel				1,000	1,700										
Container															
Stainless steel	2,640,000	5,600	50,000	165,000	750,000	900,000	270,000	500,000	42,000	3,500	260,000	50,000	70,000	9,900,000	31,000
Aluminum			660		10,000										
Other															
Concrete					30,000[d]										
Boron					500	1,000	300		29						
Silver					1,100										
Cadmium					34										
Indium					280										
Magnesium									430						
Nickel	210														
Rhodium									30						
Ruthenium									30						
Samarium													67		
Gadolinium					530	950	23								
Hafnium														600,000	

a. Source: DIRS 148240-Dirkmaat (1998, all); DIRS 104377-Dirkmaat (1998, p. 008/016, 009/016); values are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Blanks indicate none or less than reportable quantities.
d. Low density converters were added to canisters of Three Mile Island Unit 2 fuel and would remain when shipped to the repository.

Table A-23. Maximum heat generation for DOE spent nuclear fuel (watts per handling unit).[a,b]

	Category and fuel type	Maximum heat generation
1.	Uranium metal	18
2.	Uranium zirconium	90
3.	Uranium molybdenum	4
4.	Intact uranium oxide	1,000
5.	Failed/declad/aluminum clad uranium oxide	800
6.	Uranium aluminide	480
7.	Uranium silicide	1,400
8.	High-integrity thorium/uranium carbide	250
9.	Low-integrity thorium/uranium carbide	37
10.	Nongraphite plutonium/uranium carbide	1,800
11.	Mixed oxide	1,800
12.	Thorium/uranium oxide	600
13.	Uranium zirconium hydride	100
14.	Sodium-bonded	N/A[c]
15.	Naval fuel	4,250
16.	Miscellaneous	1,000

a. Sources: DIRS 104354-Dirkmaat (1997, Attachment, pp. 74 to 77); DIRS 104377-Dirkmaat (1998, Table A.2.2-3); DIRS 156933-Fillmore (2001, all).
b. Handling unit is a canister.
c. N/A = not applicable. Assumed to be treated and therefore part of high-level radioactive waste inventory (see Section A.2.2.1).

Table A-24. Required number of canisters for disposal of DOE spent nuclear fuel.[a,b]

	Hanford		INEEL		SRS	Naval	
Category	18-inch	25.3-inch	18-inch	24-inch	18-inch	Short	Long
1		440	6		9		
2			8				
3			70				
4	14	20	179	16			
5	1		406		425		
6					750		
7					225		
8			503[c]				
9			60				
10	2		3				
11	324		43				
12			24	47			
13	3		97				
14[d]							
15						200	100
16	5		39		2		
Totals	***349***	***460***	***1,438***	***63***	***1,411***	***200***	***100***

a. Sources: DIRS 104356-Dirkmaat (1997, Attachment, p. 2); Dirkmaat (DIRS 148240-1998, all).
b. INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site.
c. Includes 334 canisters from Fort St. Vrain.
d. Assumed to be treated and therefore part of high-level radioactive waste inventory (see Section A.2.2.1).

Table A-25. Preliminary naval canister design parameters.[a]

Parameter	Short canister	Long canister
Maximum outside diameter (centimeters)[b,c]	169	169
Maximum outer length (centimeters)	475	539
Minimum loaded weight (metric tons)[d]	27	27
Maximum loaded weight (metric tons)	45	45

a. Source: DIRS 104354-Dirkmaat (1997, Attachment, pp. 86 to 88).
b. To convert centimeters to inches, multiply by 0.3937.
c. Right circular cylinder.
d. To convert metric tons to tons, multiply by 1.1023.

A.2.3 HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive waste is the highly radioactive material resulting from the reprocessing of spent nuclear fuel. DOE stores high-level radioactive waste at the Hanford Site, the Savannah River Site, and the Idaho National Engineering and Environmental Laboratory. Between 1966 and 1972, commercial chemical reprocessing operations at the Nuclear Fuel Services plant near West Valley, New York, generated a small amount of high-level radioactive waste at a site presently owned by the New York State Energy Research and Development Authority. These operations ceased after 1972. In 1980, Congress passed the West Valley Demonstration Project Act, which authorizes DOE to conduct, with the Research and Development Authority, a demonstration of solidification of high-level radioactive waste for disposal and the decontamination and decommissioning of demonstration facilities (DIRS 102588-DOE 1992, Chapter 3). This section addresses defense high-level radioactive waste generated at the DOE sites (Hanford Site, Idaho National Engineering and Environmental Laboratory, and Savannah River Site) and commercial high-level radioactive waste generated at the West Valley Demonstration Project.

A.2.3.1 Background

In 1985, DOE published a report in response to Section 8 of the Nuclear Waste Policy Act (of 1982) that required the Secretary of Energy to recommend to the President whether defense high-level radioactive waste should be disposed of in a geologic repository along with commercial spent nuclear fuel. That report, *An Evaluation of Commercial Repository Capacity for the Disposal of Defense High-Level Waste* (DIRS 103492-DOE 1985, all), provided the basis, in part, for the President's determination that defense high-level radioactive waste should be disposed of in a geologic repository. Given that determination, DOE decided to allocate 10 percent of the capacity of the first repository for the disposal of DOE spent nuclear fuel (2,333 MTHM) and high-level radioactive waste (4,667 MTHM) (DIRS 104384-Dreyfuss 1995, all; DIRS 104398-Lytle 1995, all).

Calculating the MTHM quantity for spent nuclear fuel is straightforward. It is determined by the actual heavy metal content of the spent fuel. However, an equivalence method for determining the MTHM in defense high-level radioactive waste is necessary because almost all of its heavy metal has been removed. A number of alternative methods for determining MTHM equivalence for high-level radioactive waste have been considered over the years. Four of those methods are described in the following paragraphs.

Historical Method. Table 1-1 of DIRS 103492-DOE (1985) provided a method to estimate the MTHM equivalence for high-level radioactive waste based on comparing the radioactive (curie) equivalence of commercial high-level radioactive waste and defense high-level radioactive waste. The method relies on the relative curie content of a hypothetical (in the early 1980s) canister of defense high-level radioactive waste from the Savannah River, Hanford, or Idaho site, and a hypothetical canister of vitrified waste from reprocessing of high-burnup commercial spent nuclear fuel. Based on commercial high-level radioactive waste containing 2.3 MTHM per canister (heavy metal has not been removed from commercial waste) and defense high-level radioactive waste estimated to contain approximately 22 percent of the radioactivity of a canister of commercial high-level radioactive waste, defense high-level radioactive waste was estimated to contain the equivalent of 0.5 MTHM per canister. Since 1985, DOE has used this 0.5 MTHM equivalence per canister of defense high-level radioactive waste in its consideration of the potential impacts of the disposal of defense high-level radioactive waste, including the analysis presented in this EIS. With this method, less than 50 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste. There has been no determination of which waste would be shipped to the repository, or the order of shipments.

Spent Nuclear Fuel Reprocessed Method. Another method of determining MTHM equivalence, based on the quantity of spent nuclear fuel reprocessed, would be to consider the MTHM in the high-level radioactive waste to be the same as the MTHM in the spent nuclear fuel before it was reprocessed. Using this method, less than 5 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

Total Radioactivity Method. Another method, the total radioactivity method, would establish equivalence based on a comparison of radioactivity inventory (curies) of defense high-level radioactive waste to that of a standard MTHM of commercial spent nuclear fuel. For this equivalence method the standard spent nuclear fuel characteristics are based on pressurized-water reactor fuel with uranium-235 enrichment of 3.11 percent and 39.65 gigawatt-days per MTHM burnup. Using this method, 100 percent of the total inventory of high-level radioactive waste inventory could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

Radiotoxicity Method. Yet another method, the radiotoxicity method, uses a comparison of the relative radiotoxicity of defense high-level radioactive waste to that of a standard MTHM of commercial spent nuclear fuel, and is thus considered an extension of the total radioactivity method. Radiotoxicity compares the inventory of specific radionuclides to a regulatory release limit for that radionuclide, and uses these relationships to develop an overall radiotoxicity index. For this equivalence, the standard spent nuclear fuel characteristics are based on pressurized-water reactor fuel with uranium-235 enrichment of 3.11 percent, 39.65 gigawatt-days per MTHM burnup. Using this method, 100 percent of the total inventory of high-level radioactive waste could be disposed of in the repository within the 4,667 MTHM allocation for high-level radioactive waste.

A recent report (DIRS 103495-Knecht et al. 1999, all) describes four equivalence calculation methods and notes that, under the Total Radioactivity Method or the Radiotoxicity Method, all DOE high-level radioactive waste could be disposed of under the Proposed Action. Using different equivalence methods would shift the proportion of high-level radioactive waste that could be disposed of between the Proposed Action and Inventory Module 1 analyzed in Chapter 8, but would not change the cumulative impacts analyzed in this EIS. Regardless of the equivalence method used, the EIS analyzes the impacts from disposal of the entire inventory of high-level radioactive waste in inventory Module 1.

A.2.3.2 Sources

A.2.3.2.1 *Hanford Site*

The Hanford high-level radioactive waste materials discussed in this EIS include tank waste, strontium capsules, and cesium capsules (DIRS 104406-Picha 1997, Table RL-1). DOE has not declared other miscellaneous materials or waste at Hanford, either existing or forecasted, to be candidate high-level radioactive waste streams. Before shipment to the repository, DOE would vitrify the high-level radioactive waste into a borosilicate glass matrix and pour it into stainless-steel canisters.

A.2.3.2.2 *Idaho National Engineering and Environmental Laboratory*

The Idaho National Engineering and Environmental Laboratory has proposed three different high-level radioactive waste stream matrices for disposal at the proposed Yucca Mountain Repository—glass, ceramic, and metal. The glass matrix waste stream would come from the Idaho Nuclear Technology and Engineering Center and would consist of wastes generated from the treatment of irradiated nuclear fuels. The ongoing Argonne National Laboratory-West electrometallurgical treatment of DOE sodium-bonded fuels will generate both ceramic and metallic high-level radioactive waste matrices. DOE is developing the *Idaho High-Level Waste and Facilities Disposition Final Environmental Impact Statement* (see DIRS 155100-DOE 1999, all), to support decisions on managing the high-level radioactive waste at the Idaho Nuclear Technology and Engineering Center.

A.2.3.2.3 *Savannah River Site*

Savannah River Site high-level radioactive waste consists of wastes generated from the treatment of irradiated nuclear fuels. These wastes include various chemicals, radionuclides, and fission products that DOE maintains in liquid, sludge, and saltcake forms. The Defense Waste Processing Facility at the Savannah River Site mixes the high-level radioactive waste with glass-forming materials, converts it to a durable borosilicate glass waste form, pours it into stainless-steel canisters, and seals the canisters with welded closure plugs (DIRS 104406-Picha 1997, Attachment 4, p. 2).

Another source of high-level radioactive waste at the Savannah River Site is the immobilized plutonium addressed in Section A.2.4.

A.2.3.2.4 *West Valley Demonstration Project*

The West Valley Demonstration Project is responsible for solidifying high-level radioactive waste that remains from the commercial spent nuclear fuel reprocessing plant operated by Nuclear Fuel Services. The Project mixes the high-level radioactive waste with glass-forming materials, converts it to a durable borosilicate glass waste form, pours it into stainless-steel canisters, and seals the canisters with welded closure plugs.

A.2.3.3 Present Status

A.2.3.3.1 *Hanford Site*

The Hanford Site stores high-level radioactive waste in underground carbon-steel tanks. This analysis assumed that before vitrification, strontium and cesium capsules currently stored in water basins at Hanford would be blended with the liquid high-level radioactive waste. To date, Hanford has immobilized no high-level radioactive waste. Before shipping waste to a repository, DOE would vitrify it into an acceptable glass form. DOE has scheduled vitrification to begin in 2007 with an estimated completion in 2028.

A.2.3.3.2 *Idaho National Engineering and Environmental Laboratory*

Most of the high-level radioactive waste at the Idaho Nuclear Technology and Engineering Center (formerly the Idaho Chemical Processing Plant) is in calcined solids (calcine) stored at the Idaho National Engineering and Environmental Laboratory. The calcine, an interim waste form, is in stainless-steel bins in concrete vaults. Before shipment to a repository, DOE proposes to immobilize the high-level radioactive waste in a vitrified (glass) waste form. The Idaho Nuclear Technology and Engineering Center proposes to implement its vitrification program in 2020 and complete it in 2035 (DIRS 103497-INEEL 1998, pp. A-39 to A-42).

As discussed in Section A.2.2.1, Argonne National Laboratory-West began electrometallurgical treatment of EBR-II reactor fuel in 2000. The ceramic and metallic waste forms being produced will be stored onsite.

A.2.3.3.3 *Savannah River Site*

DOE stores high-level radioactive waste in underground tanks at the Savannah River Site. High-level radioactive waste that has been converted to a borosilicate glass form and DOE projects completion of the vitrification of the stored high-level radioactive waste by 2027 (DIRS 157008-DOE 2001, all).

A.2.3.3.4 *West Valley Demonstration Project*

High-level radioactive waste is stored in underground tanks at the West Valley site. High-level radioactive waste that has been converted into a borosilicate glass waste form is stored onsite. West Valley plans to complete its vitrification program by the Fall of 2002 (DIRS 102588-DOE 1992, Chapter 3).

A.2.3.4 Final Waste Form

The final waste form for high-level radioactive waste from the Hanford Site, Savannah River Site, Idaho Nuclear Technology and Engineering Center, and West Valley Demonstration Project would be a vitrified glass matrix in a stainless-steel canister.

The waste forms from Argonne National Laboratory-West will be ceramic and metallic waste matrices and will be in stainless-steel canisters similar to those used for Savannah River Site and Idaho Nuclear Technology and Engineering Center glass wastes.

A.2.3.5 Waste Characteristics

A.2.3.5.1 *Mass and Volume*

Hanford Site. The estimated volume of borosilicate glass generated by high-level radioactive waste disposal actions at Hanford will be 15,700 cubic meters (554,000 cubic feet); the estimated mass of the glass is 44,000 metric tons (48,500 tons) (DIRS 104407-Picha 1998, Attachment 1). The volume calculation assumes that strontium and cesium compounds from capsules currently stored in water basins would be blended with tank wastes before vitrification with no increase in product volume. This volume of glass could require as many as 14,500 canisters, nominally 4.5 meters (15 feet) long with a 0.61-meter (2-foot) diameter (DIRS 104407-Picha 1998, Attachment 1).

Idaho National Engineering and Environmental Laboratory. Table A-26 lists the volumes, masses, densities, and estimated number of canisters for the three proposed waste streams.

Savannah River Site. Based on Revision 8 of the High-Level Waste System Plan (DIRS 101904-Davis and Wells 1997, all), the Savannah River Site would generate an estimated 5,978 canisters of high-level radioactive waste (DIRS 104406-Picha 1997, Attachment 1). The canisters have a nominal outside diameter of 0.61 meter (2 feet) and a nominal height of 3 meters (10 feet). They would contain a total of approximately 4,240 cubic meters (150,000 cubic feet) of glass. The estimated total mass of high-level radioactive waste for repository disposal would be 11,600 metric tons (12,800 tons) (DIRS 104406-Picha 1997, Attachment 1). DOE has addressed the additional high-level radioactive waste canisters that DOE

Table A-26. Physical characteristics of high-level radioactive waste at the Idaho National Engineering and Environmental Laboratory.[a,b]

Physical quantities	INTEC glass matrix	ANL-W ceramic matrix	ANL-W metal matrix
Volume (cubic meters)[c]	743	60.0	1.2
Mass (kilograms)[d]	1,860,000	144,000	9,000
Density (kilograms per cubic meter)	2,500	2,400	7,750
Number of canisters [range][e]	1,190	96 [80 - 125]	6 [2 - 10]

a. Sources: DIRS 104406-Picha (1997, Attachment 1, Table ID-2); DIRS 104389-Goff (1998, all); DIRS 104392-Goff (1998, all).
b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.
c. To convert cubic meters to cubic yards, multiply by 1.3079.
d. To convert kilograms to pounds, multiply by 2.2046.
e. Canister would be nominally 3 meters (10 feet) by 0.61 meter (2 feet). Canisters would be filled to approximately 0.625 cubic meter (22 cubic feet).

would generate at the Savannah River Site as a result of immobilizing surplus plutonium (DIRS 118979-DOE 1999, p. 2-29). As discussed in DIRS 118979-DOE (1999, p. 2-29), 101 additional canisters would be required if the assumed one-third of the plutonium is immobilized. If the entire inventory of surplus plutonium was immobilized, 272 additional high-level radioactive waste canisters would be required.

West Valley Demonstration Project. The West Valley Demonstration Project will generate between 260 and 300 canisters of high-level radioactive waste. The canisters have a nominal outside diameter of 0.61 meter (2 feet) and a nominal height of 3 meters (10 feet) (DIRS 104406-Picha 1997, Attachment 1). They will contain approximately 200 cubic meters (7,060 cubic feet) of glass. The estimated total mass of this high-level radioactive waste will be between 540 and 630 metric tons (595 and 694 tons) (DIRS 104413-Picha 1998, p. 3).

Summary. Table A-27 summarizes the information in the previous paragraphs to provide the estimated total mass and volume projected to be disposed of at the repository.

Table A-27. High-level radioactive waste mass and volume summary.

Parameter	Total[a,b]
Mass	58,000 metric tons
Volume	21,000 cubic meters
Number of canisters	22,147 - 22,280[c]

a. Sources: DIRS 104406-Picha (1997, Attachment 1); DIRS 104407-Picha (1998, Attachment 1).
b. To convert metric tons to tons, multiply by 1.1023; to convert cubic meters to cubic yards, multiply by 1.3079.
c. The number of canisters depends on the amount of surplus weapons-usable plutonium immobilized (see Section A.2.4.5.2.1).

A.2.3.5.2 *Amount and Nature of Radioactivity*

The following paragraphs present radionuclide inventory information for the individual sites. They present the best available data at varying dates; however, in most cases, the data are conservative because the inventories are for dates earlier than the date of disposal, and additional radioactive decay would occur before disposal. Any differences due to varying amounts of radioactive decay are small.

Hanford Site. Table A-28 lists the estimated radionuclide inventory for Hanford high-level radioactive glass waste, including strontium-90 and cesium-137 currently stored in capsules (DIRS 104406-Picha 1997, Table RL-1). With the exception of hydrogen-3 and carbon-14, this table makes the conservative assumption that 100 percent of a radionuclide in Hanford’s 177 tanks and existing capsules is vitrified.

Table A-28. Radionuclide distribution for Hanford Site high-level radioactive waste.[a,b]

Radionuclide[c]	Total curies	Curies per canister	Radionuclide	Total curies	Curies per canister
Hydrogen-3	--[d]	--	Thorium-229	1.8	1.3×10^{-4}
Carbon-14	9.6×10^{-2}	6.6×10^{-6}	Thorium-230	--	--
Chlorine-36	--	--	Thorium-232	2.1	1.5×10^{-4}
Nickel-59	9.3×10^{2}	6.4×10^{-2}	Protactinium-231	1.6×10^{2}	1.1×10^{-2}
Nickel-63	9.2×10^{4}	6.3	Uranium-232	1.2×10^{2}	8.5×10^{-3}
Cobalt-60	1.2×10^{4}	8.5×10^{-1}	Uranium-233	4.8×10^{2}	3.3×10^{-2}
Selenium-79	7.7×10^{2}	5.3×10^{-2}	Uranium-234	3.5×10^{2}	2.4×10^{-2}
Krypton-85	--	--	Uranium-235	1.5×10^{1}	1.0×10^{-3}
Strontium-90	9.7×10^{7}	6.7×10^{3}	Uranium-236	9.6	6.6×10^{-4}
Niobium-93m	2.7×10^{3}	1.9×10^{-1}	Uranium-238	3.2×10^{2}	2.2×10^{-2}
Niobium-94	--	--	Neptunium-237	1.4×10^{2}	9.7×10^{-3}
Zirconium-93	3.6×10^{3}	2.5×10^{1}	Plutonium-238	2.1×10^{3}	1.9×10^{-1}
Technetium-99	3.3×10^{4}	2.3	Plutonium-239	4.7×10^{4}	2.7
Rhodium-101	--	--	Plutonium-240	9.9×10^{3}	6.2×10^{-1}
Rhodium-102	--	--	Plutonium-241	2.3×10^{5}	1.6×10^{1}
Ruthenium-106	1.0×10^{5}	7.2	Plutonium-242	1.2	8.0×10^{-5}
Palladium-107	--	--	Americium-241	7.0×10^{4}	4.8
Tin-126	1.2×10^{3}	8.2×10^{-2}	Americium-242m	--	--
Iodine-129	3.2×10^{1}	2.2×10^{-3}	Americium-243	9.3	6.4×10^{-4}
Cesium-134	8.9×10^{4}	6.1	Curium-242	7.7×10^{1}	5.3×10^{-3}
Cesium-135	--	--	Curium-243	1.0×10^{1}	6.9×10^{-4}
Cesium-137	1.1×10^{8}	7.7×10^{3}	Curium-244	2.4×10^{2}	1.7×10^{-2}
Samarium-151	2.8×10^{6}	1.9×10^{2}	Curium-245	--	--
Lead-210	--	--	Curium-246	--	--
Radium-226	6.3×10^{-2}	4.4×10^{-6}	Curium-247	--	--
Radium-228	7.7×10^{1}	5.3×10^{-3}	Curium-248	--	--
Actinium-227	8.8×10^{1}	6.0×10^{-3}	Californium-252	--	--

a. Sources: DIRS 104406-Picha (1997, Table RL-1); DIRS 104407-Picha (1998, Attachment 1).
b. Decayed to January 1, 1994.
c. Half-lives are listed in Tables A-11 and footnote g of Table A-21, with the exception of lead-210 = 23 years, rhodium-101 = 3.3 years, radium-226 = 1.6×10^{3} years, and radium 228 = 5.7 years.
d. -- = not found in appreciable quantities.

Consistent with Hanford modeling for the Integrated Data Base (DIRS 101815-DOE 1997, p. 2-24), pretreatment and vitrification would separate hydrogen-3 and carbon-14 from the high-level radioactive waste stream such that essentially 0.0 percent and 0.002 percent of each, respectively, would be present in the glass. A large portion of iodine-129 could also be separated, but the analysis assumed a conservative 50-percent retention (DIRS 104407-Picha 1998, Attachment 1). Table A-28 uses the estimated number of canisters (14,500) to develop the curies-per-canister value.

Idaho National Engineering and Environmental Laboratory. Table A-29 contains a baseline radionuclide distribution for the three Idaho National Engineering and Environmental Laboratory high-level radioactive waste streams. For each waste stream, the total radionuclide inventory is provided, as is the worst-case value for curies per canister. For Idaho Nuclear Technology and Engineering Center glass, the calculated inventories are decayed to 2035. For Argonne National Laboratory-West waste matrices, the calculated inventories are decayed to 2000.

Savannah River Site. The Waste Qualification Report details the projected radionuclide distribution in the high-level radioactive waste from the Savannah River Site (DIRS 101908-Plodinec and Marra 1994, p. 10). Table A-30 lists the quantities of individual radionuclides decayed to 2015. The curie-per-canister values were obtained by dividing the total radionuclide projection by the expected number of canisters (5,978).

Table A-29. Radionuclide distribution for Idaho National Engineering and Environmental Laboratory high-level radioactive waste.[a,b]

	INTEC glass		ANL-W ceramic[d]		ANL-W metal[d]	
Radionuclides[c]	Total curies for 2035	Curies per canister[d]	Total curies for 2000	Curies per canister[e]	Total curies for 2000	Curies per canister[e]
Hydrogen-3	3.6×10^{3}	4.3	--[f]	--	--	--
Carbon-14	2.8×10^{-2}	8.3×10^{-5}	--	--	4.3	4.3
Chlorine-36	--	--	--	--	--	--
Cobalt-60	3.2×10^{1}	3.6×10^{-2}	--	--	3.2×10^{3}	3.2×10^{3}
Nickel-59	--	--	--	--	1.1×10^{1}	1.1×10^{1}
Nickel-63	--	--	--	--	4.1×10^{2}	3.9×10^{2}
Selenium-79	--	--	--	--	--	--
Krypton-85	--	--	--	--	--	--
Strontium-90	7.0×10^{6}	1.2×10^{4}	7.1×10^{5}	4.7×10^{4}	--	--
Niobium-93	4.7×10^{2}	1.4	--	--	2.9×10^{1}	2.9×10^{1}
Niobium-94	5.4×10^{-3}	1.6×10^{-5}	--	--	2.7	2.7
Zirconium-93	--	--	--	--	--	--
Technetium-99	3.4×10^{3}	9.9	--	--	1.3×10^{2}	1.3×10^{2}
Rhodium-101	--	--	--	--	--	--
Rhodium-102	2.0×10^{-5}	2.2×10^{-8}	--	--	--	--
Ruthenium-106	1.0×10^{-9}	8.7×10^{-13}	--	--	2.1×10^{4}	2.1×10^{4}
Palladium-107	--	--	--	--	--	--
Tin-126	8.9×10^{1}	2.6×10^{-1}	--	--	2.8	2.1
Iodine-129	5.6	1.7×10^{-2}	3.4×10^{-1}	1.8×10^{-2}	--	--
Cesium-134	3.3×10^{-2}	3.6×10^{-5}	7.9×10^{3}	5.1×10^{2}	--	--
Cesium-135	1.6×10^{2}	2.5×10^{-1}	1.6×10^{1}	8.8×10^{-1}	--	--
Cesium-137	6.0×10^{6}	1.2×10^{4}	8.5×10^{5}	5.3×10^{4}	--	--
Samarium-151	--	--	--	--	--	--
Lead-210	--	--	--	--	--	--
Radium-226	9.7×10^{-3}	7.2×10^{-5}	3.0×10^{-5}	2.1×10^{-6}	--	--
Radium-228	--	--	--	--	--	--
Actinium-227	--	--	--	--	--	--
Thorium-229	--	--	--	--	--	--
Thorium-230	4.0×10^{-1}	2.8×10^{-3}	4.7×10^{-3}	8.9×10^{-4}	--	--
Thorium-232	9.9×10^{-8}	5.0×10^{-10}	2.3×10^{-9}	1.3×10^{-10}	--	--
Protactinium-231	--	--	--	--	--	--
Uranium-232	4.6×10^{-3}	5.2×10^{-6}	2.6×10^{-3}	1.8×10^{-4}	1.2×10^{-4}	1.2×10^{-4}
Uranium-233	1.3×10^{-3}	6.1×10^{-6}	2.0×10^{-4}	1.4×10^{-5}	5.8×10^{-5}	5.8×10^{-5}
Uranium-234	1.0×10^{2}	1.1×10^{-1}	2.8	1.9×10^{-1}	7.7×10^{-1}	7.7×10^{-1}
Uranium-235	5.9×10^{-1}	6.6×10^{-4}	8.8×10^{-2}	5.9×10^{-3}	2.5×10^{-2}	2.5×10^{-2}
Uranium-236	1.5	1.7×10^{-3}	6.3×10^{-2}	4.2×10^{-3}	1.8×10^{-2}	1.8×10^{-2}
Uranium-238	2.9×10^{-2}	3.3×10^{-5}	2.8×10^{-1}	4.9×10^{-3}	9.7×10^{-2}	8.8×10^{-2}
Neptunium-237	6.3	2.8×10^{-2}	1.3	5.8×10^{-2}	2.4×10^{-5}	2.3×10^{-5}
Plutonium-238	9.0×10^{4}	1.0×10^{2}	3.6×10^{2}	2.9×10^{1}	6.6×10^{-3}	6.6×10^{-3}
Plutonium-239	1.8×10^{3}	2.0	1.7×10^{4}	8.1×10^{2}	3.3×10^{-1}	3.3×10^{-1}
Plutonium-240	1.6×10^{3}	1.8	1.5×10^{3}	6.9×10^{1}	2.9×10^{-2}	2.9×10^{-2}
Plutonium-241	1.9×10^{4}	2.2×10^{1}	1.1×10^{4}	1.3×10^{3}	1.9×10^{-1}	1.9×10^{-1}
Plutonium-242	3.4	3.8×10^{-3}	1.2×10^{-1}	2.3×10^{-2}	2.0×10^{-6}	2.0×10^{-6}
Americium-241	1.3×10^{4}	1.4×10^{1}	1.6×10^{3}	3.4×10^{1}	3.1×10^{-2}	2.1×10^{-2}
Americium-242/242m	1.5×10^{-2}	9.4×10^{-5}	1.4×10^{1}	2.1×10^{-1}	2.7×10^{-4}	2.1×10^{-4}
Americium-243	1.4×10^{-2}	1.1×10^{-4}	2.8×10^{-1}	1.9×10^{-2}	4.8×10^{-6}	4.8×10^{-6}
Curium-242	1.2×10^{-2}	7.7×10^{-5}	1.2×10^{1}	1.8×10^{-1}	2.3×10^{-4}	1.8×10^{-4}
Curium-243	4.7×10^{-4}	3.4×10^{-6}	1.6×10^{-1}	3.1×10^{-3}	3.0×10^{-6}	2.1×10^{-6}
Curium-244	1.0×10^{-2}	7.7×10^{-5}	1.9	1.3×10^{-1}	3.1×10^{-5}	3.1×10^{-5}
Curium-245	3.7×10^{-6}	2.8×10^{-8}	6.8×10^{-5}	4.7×10^{-6}	1.1×10^{-9}	1.1×10^{-9}
Curium-246	8.7×10^{-8}	6.6×10^{-10}	4.2×10^{-7}	2.9×10^{-8}	7.1×10^{-12}	7.1×10^{-12}
Curium-247	3.1×10^{-14}	2.4×10^{-16}	2.4×10^{-13}	1.6×10^{-14}	4.0×10^{-18}	4.0×10^{-18}
Curium-248	9.4×10^{-15}	7.2×10^{-17}	2.6×10^{-14}	1.8×10^{-15}	4.4×10^{-19}	4.4×10^{-19}
Californium-252	--	--	6.5×10^{-19}	1.6×10^{-19}	--	--

a. Sources: DIRS 104406-Picha (1997, Table ID-2); DIRS 104389-Goff (1998, all).
b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.
c. Half-lives are listed in Tables A-11, footnote g of Table A-21, and footnote c of Table A-28.
d. Matrices based on treating all sodium-bonded fuels. Curie values based on calculated data from stored material.
e. Curie per canister values were provided as worst case rather than a homogenous mixture.
f. -- = not found in appreciable quantities.

Table A-30. Radionuclide distribution for Savannah River Site high-level radioactive waste (2015).[a]

Radionuclide[b]	Total (curies)	Curies per canister	Radionuclide	Total (curies)	Curies per canister
Hydrogen-3	--[c]	--	Thorium-229	--	--
Carbon-14	--	--	Thorium-230	2.4×10^{-2}	4.0×10^{-6}
Chlorine-36	--	--	Thorium-232	--	--
Nickel-59	1.1×10^{2}	1.8×10^{-2}	Protactinium-231	--	--
Nickel-63	1.2×10^{4}	2.1	Uranium-232	--	--
Cobalt-60[c]	--	4.5×10^{1}	Uranium-233	--	--
Selenium-79	1.1×10^{3}	1.8×10^{-1}	Uranium-234	1.6×10^{2}	2.7×10^{-2}
Krypton-85	--	--	Uranium-235	--	--
Strontium-90	1.7×10^{8}	2.9×10^{4}	Uranium-236	--	--
Niobium-93m	1.3×10^{4}	2.2	Uranium-238	5.0×10^{1}	8.3×10^{-3}
Niobium-94	--	--	Neptunium-237	4.1×10^{2}	6.8×10^{-2}
Zirconium-93	3.0×10^{4}	5.0	Plutonium-238	3.0×10^{6}	5.0×10^{2}
Technetium-99	1.5×10^{4}	2.5	Plutonium-239	3.7×10^{4}	6.2
Rhodium-101	--	--	Plutonium-240	2.5×10^{4}	4.1
Rhodium-102	--	--	Plutonium-241	3.3×10^{6}	5.4×10^{2}
Ruthenium-106[d]	--	2.4	Plutonium-242	3.5×10^{1}	5.8×10^{-3}
Palladium-107	7.3×10^{1}	1.2×10^{-2}	Americium-241	1.6×10^{5}	2.6×10^{1}
Tin-126	2.6×10^{3}	4.3×10^{-1}	Americium-242m	--	--
Iodine-129	--	--	Americium-243	1.1×10^{3}	1.8×10^{-1}
Cesium-134[d]	--	1.2×10^{1}	Curium-242	--	--
Cesium-135	4.0×10^{2}	6.7×10^{-2}	Curium-243	--	--
Cesium-137	1.5×10^{8}	2.4×10^{4}	Curium-244	4.9×10^{5}	8.3×10^{1}
Samarium-151	3.3×10^{6}	5.5×10^{2}	Curium-245	--	--
Lead-210	--	--	Curium-246	--	--
Radium-226	--	--	Curium-247	--	--
Radium-228	--	--	Curium-248	--	--
Actinium-227	--	--	Californium-252	--	--

a. Sources: DIRS 101908-Plodinec and Marra (1994, p. 10); DIRS 104403-Pearson (1998, all).
b. Half-lives are listed in Tables A-11, footnote g of Table A-21, and footnote c of Table A-28.
c. -- = not found in appreciable quantities.
d. Total curie content not provided for these nuclides; curie per canister values provided for 10 years after production.

West Valley Demonstration Project. DOE used the ORIGEN2 computer code to estimate the radionuclide inventory for the West Valley Demonstration Project, simulating each Nuclear Fuel Services irradiated fuel campaign. A detailed description of the development of these estimates is in the West Valley Demonstration Project Waste Qualification Report (DIRS 103500-WVNS n.d., WQR-1.2, Appendix 1, Rev. 1). Table A-31 lists the estimated activity by nuclide and provides the total curies, as well as the curies per canister, based on 260 canisters.

A.2.3.5.3 *Chemical Composition*

Hanford Site. The Integrated Data Base (DIRS 101815-DOE 1997, p. 2-29) provides the best available information for the proposed representative chemical composition of future high-level radioactive waste glass from Hanford. Table A-32 combines the percentages by weight of chemical constituents obtained from the Integrated Data Base with the estimated mass to present the expected chemical composition of the glass in terms of mass per chemical compound.

Idaho National Engineering and Environmental Laboratory

Idaho Nuclear Technology and Engineering Center Glass Matrix. This waste stream is composed of three primary sources—zirconium calcine, aluminum calcine, and sodium-bearing waste.

Table A-31. Radionuclide distribution for West Valley Demonstration Project high-level radioactive waste (2015).[a]

Radionuclide[b]	Total curies	Curies per canister	Radionuclide	Total curies	Curies per canister
Hydrogen-3	2.0×10^{1}	7.8×10^{-2}	Thorium-229	2.3×10^{-1}	8.9×10^{-4}
Carbon-14	1.4×10^{2}	5.3×10^{-1}	Thorium-230	6.0×10^{-2}	2.3×10^{-4}
Chlorine-36	--[c]	--	Thorium-232	1.6	6.3×10^{-3}
Nickel-59	1.1×10^{2}	4.1×10^{-1}	Protactinium-231	1.5×10^{1}	5.9×10^{-2}
Nickel-63	7.1×10^{3}	2.7×10^{1}	Uranium-232	5.9	2.3×10^{-2}
Cobalt-60	2.9×10^{1}	1.1×10^{-1}	Uranium-233	9.5	3.7×10^{-2}
Selenium-79	6.0×10^{1}	2.3×10^{-1}	Uranium-234	5.0	1.9×10^{-2}
Krypton-85	--	--	Uranium-235	1.0×10^{-1}	3.9×10^{-4}
Strontium-90	3.7×10^{6}	1.4×10^{4}	Uranium-236	3.0×10^{-1}	1.1×10^{-3}
Niobium-93m	2.5×10^{2}	9.5×10^{-1}	Uranium-238	8.5×10^{-1}	3.3×10^{-3}
Niobium-94	--	--	Neptunium-237	2.4×10^{1}	9.2×10^{-2}
Zirconium-93	2.7×10^{2}	1.1	Plutonium-238	7.0×10^{3}	2.7×10^{1}
Technetium-99	1.7×10^{3}	6.5	Plutonium-239	1.7×10^{3}	6.4
Rhodium-101	--	--	Plutonium-240	1.2×10^{3}	4.7
Rhodium-102	--	--	Plutonium-241	2.5×10^{4}	9.5×10^{1}
Ruthenium-106	5.0×10^{-7}	1.9×10^{-9}	Plutonium-242	1.7	6.4×10^{-3}
Palladium-107	1.1×10^{1}	4.2×10^{-2}	Americium-241	5.3×10^{4}	2.0×10^{2}
Tin-126	1.0×10^{2}	4.0×10^{-1}	Americium-242m	2.7×10^{2}	1.0
Iodine-129	2.1×10^{-1}	8.1×10^{-4}	Americium-243	3.5×10^{2}	1.3
Cesium-134	1.2	4.4×10^{-3}	Curium-242	2.2×10^{2}	8.4×10^{-1}
Cesium-135	1.6×10^{2}	6.2×10^{-1}	Curium-243	7.3×10^{1}	2.8×10^{-1}
Cesium-137	4.1×10^{6}	1.6×10^{4}	Curium-244	2.9×10^{3}	1.1×10^{1}
Samarium-151	7.0×10^{4}	2.7×10^{2}	Curium-245	8.8×10^{-1}	3.4×10^{-3}
Lead-210	--	--	Curium-246	1.0×10^{-1}	3.9×10^{-4}
Radium-226	--	--	Curium-247	--	--
Radium-228	1.6	6.3×10^{-3}	Curium-248	--	--
Actinium-227	1.2×10^{1}	4.6×10^{-2}	Californium-252	--	--

a. Source: DIRS 103500-WVNS (n.d., WQR-1.2, Appendix 1, Rev. 1).
b. Half-lives are listed in Tables A-11, A-21, and A-28.
c. -- = not found in appreciable quantities.

Table A-32. Expected chemical composition of Hanford high-level radioactive waste glass (kilograms).[a,b]

Compound	Mass	Compound	Mass
Aluminum oxide	4,100,000	Sodium oxide	5,190,000
Boron oxide	3,090,000	Sodium sulfate	44,000
Bismuth trioxide	510,000	Nickel monoxide	480,000
Calcium oxide	370,000	Phosphorous pentaoxide	690,000
Ceric oxide	500,000	Lead monoxide	62,000
Chromic oxide	160,000	Silicon oxide	20,300,000
Ferric oxide	1,980,000	Strontium oxide	79,000
Potassium oxide	75,000	Thorium dioxide	4,400
Lanthanum oxide	48,000	Uranium oxide	2,940,000
Lithium oxide	880,000	Zirconium dioxide	1,630,000
Manganese dioxide	510,000	Other	75,000
Sodium fluoride	280,000	***Total***	***44,000,000***

a. Sources: DIRS 101815-DOE (1997, p. 2-29); DIRS 104407-Picha (1998, Attachment 1).
b. To convert kilograms to pounds, multiply by 2.2046.

The distribution of these sources is 55 percent, 15 percent, and 30 percent, respectively (DIRS 104395-Heiser 1998, all). Table A-33 lists the chemical composition of the total waste stream.

Table A-33. Expected glass matrix chemical composition at Idaho Nuclear Technology and Engineering Center (kilograms).[a,b]

Compound or element	Mass	Compound or element	Mass
Aluminum oxide	130,000	Silicon oxide	1,020,000
Ammoniummolybdophosphate	26,000	Zirconium dioxide	18,000
Boron oxide	200,000	Arsenic	100
Calcium fluoride	140,000	Cadmium	42,000
Calcium oxide	4,100	Chromium	14,000
Ceric oxide	300	Mercury[c]	200
Ferric oxide	800	Nickel	1,400
Sodium oxide	250,000	Lead	1,800
Phosphorous pentaoxide	1,000	***Total***[d]	***1,860,000***

a. Sources: DIRS 104406-Picha (1997, Table ID-3); DIRS 104395-Heiser (1998, all).
b. Masses are rounded to the nearest 100 kilograms; to convert kilograms to pounds, multiply by 2.2046.
c. Assumes only 0.1 percent capture of original mercury in the feed materials.
d. Trace amounts of antimony, beryllium, barium, selenium, silver, and thallium were also reported.

Argonne National Laboratory-West Ceramic and Metal Matrices. Electrometallurgical processing of DOE spent nuclear fuel containing thermal-bond sodium results in two high-level radioactive waste forms for repository disposal. The first form is a glass-bonded ceramic composite. It stabilizes the alkali, alkaline earth, lanthanide, halide, and transuranic materials in processed spent nuclear fuel. These elements are present as halides after fuel treatment. For disposal, these compounds are stabilized in a zeolite-based material (DIRS 104389-Goff 1998, all).

The chemical formula for zeolite-4A, the typical starting material, is $Na_{12}[(AlO_2)_{12}(SiO_2)_{12}]$. In the waste form, zeolite contains approximately 10 to 12 percent of the halide compounds by weight. The zeolite mixture typically is combined with 25-percent glass frit by weight, placed in a stainless-steel container, and processed into a solid monolith. The zeolite is converted to the mineral sodalite in the process (DIRS 104389-Goff 1998, all). Table A-34 lists the composition of the waste form.

Table A-34. Ceramic waste matrix chemical composition at Argonne National Laboratory-West (kilograms).[a,b]

Component	Mass	Component	Mass
Zeolite-4A	92,000	Potassium iodide	10
Silicon oxide	24,000	Cesium chloride	160
Boron oxide	6,800	Barium chloride	70
Aluminum oxide	2,500	Lanthium chloride	90
Sodium oxide	2,700	Ceric chloride	140
Potassium oxide	140	Praseodymium chloride	70
Lithium-potassium chloride	13,000	Neodymium chloride	240
Sodium chloride	980	Samarium chloride	40
Rubidium chloride	20	Yttrium chloride	60
Strontium chloride	70	***Total***[c]	***144,000***

a. Source: DIRS 104389-Goff (1998, all), DIRS 104392-Goff (1998, all).
b. To convert kilograms to pounds, multiply by 2.2046.
c. Includes trace amounts of potassium bromide and europium chloride.

The halide composition would depend on the fuel processed. The final bulk composition of the ceramic waste form by weight percentages would be 25 percent glass, 63 to 65 percent zeolite-4A, and 10 to 12 percent halide salts.

Table A-35 lists the estimated composition of the second high-level radioactive waste form, which is a metal matrix waste form. The table combines percentage weight distribution with the total expected mass of the metal waste form to achieve a distributed mass by element (DIRS 104389-Goff 1998, all).

Table A-35. Expected metal waste matrix chemical composition at Argonne National Laboratory-West (kilograms).[a]

Component	Mass
Iron	4,200
Chromium	1,500
Nickel	1,100
Manganese	180
Molybdenum	220
Silicon	90
Zirconium	1,400
NMFPs[b]	360
Others[c]	20
Total	***9,000***

a. Source: DIRS 104389-Goff (1998, all); to convert kilograms to pounds, multiply by 2.2046.
b. NMFPs = Noble metal fission products; includes silver, niobium, palladium, rhodium, ruthenium, antimony, tin, tantalum, technetium, and cobalt in small amounts.
c. Others include trace amounts of carbon, phosphorus, and sulfur.

Savannah River Site. Fowler et al. (DIRS 101829-1995, p. 4) describes the chemical composition of the Defense Waste Processing Facility glass in detail. Table A-36 lists the distributed mass of the chemical constituents that comprise the current design-basis glass for the Savannah River Site. These values are based on a total mass of the glass of 11,600 metric tons (12,800 tons) (DIRS 104406-Picha 1997, Attachment 1).

West Valley Demonstration Project. The West Valley Demonstration Project will produce a single type of vitrified high-level radioactive waste. West Valley Nuclear Services Company provides a target composition for all chemical constituents in the high-level radioactive waste (DIRS 103500-WVNS n.d., WQR-1.1, Rev. 1, p. 7). Table A-37 lists the expected chemical composition based on this target composition and the upper range of the projected total glass mass, 630 metric tons (694 tons).

A.2.3.5.4 *Thermal Output*

Hanford Site. The estimated total thermal power from radioactive decay in the 14,500 reference canisters would be 1,190 kilowatts (as of January 1, 1994). This total heat load equates to an average power of 82 watts per canister. These values represent the hypothetical situation in which washed sludges from 177 tanks, cesium concentrates from the decontamination of low-level supernates, and strontium and cesium materials from capsules would be uniformly blended before vitrification. Realistically, uniform blending would not be likely. Current planning calls for merging all capsule materials with tank wastes from 2013 through 2016, which would create much hotter canisters during these years. In the extreme, the nonuniform blending of cesium concentrates and capsule materials into a relatively small volume of sludge waste could produce a few canisters with specific powers as high as 1,500 watts, which is the expected maximum for the nominally 4.5-meter (15-foot) Hanford canisters in the Civilian Radioactive Waste Management System Baseline (DIRS 104406-Picha 1997, Attachment 1, p. 2; DIRS 104476-Taylor 1997, all).

Idaho National Engineering and Environmental Laboratory. The Laboratory has three proposed high-level radioactive waste streams. Table A-38 lists the thermal output of these waste streams per waste canister.

Table A-36. Expected Savannah River Site high-level radioactive waste chemical composition (kilograms).[a,b]

Glass component	Mass	Glass component	Mass
Aluminum oxide	460,000	Sodium chloride	22,000
Barium sulfate	31,000	Neodymium	13,000
Calcium oxide	110,000	Nickel monoxide	100,000
Calcium sulfate	9,300	Neptunium	100
Cadmium	140	Promethium	210
Cerium	6,800	Praseodymium	3,300
Chromic oxide	14,000	Rubidium	120
Cesium oxide	14,000	Selenium	270
Copper oxide	51,000	Silicon oxide	5,800,000
Europium	200	Samarium	2,200
Ferric oxide	1,200,000	Tin	120
Potassium oxide	450,000	Tellurium	2,200
Lanthanum	3,500	Thorium dioxide	22,000
Lithium oxide	510,000	Titanium dioxide	100,000
Magnesium oxide	160,000	Uranium oxide	250,000
Manganese oxide	230,000	Zirconium	13,000
Molybdenum	14,000	Other[c]	58,000
Sodium oxide	1,000,000		
Sodium sulfate	12,000	***Total***	***11,600,000***

a. Sources: DIRS 101829-Fowler et al. (1995, p. 4); DIRS 104406-Picha (1997, Attachment 1).
b. To convert kilograms to pounds, multiply by 2.2046.
c. Includes trace amounts of silver, americium, cobalt, and antimony.

Table A-37. Expected West Valley Demonstration Project chemical composition (kilograms).[a,b]

Compound	Mass	Compound	Mass
Aluminum oxide	38,000	Nickel monoxide	1,600
Boron oxide	82,000	Phosphorous pentaoxide	7,600
Barium oxide	1,000	Rubidium oxide	500
Calcium oxide	3,000	Silicon oxide	260,000
Ceric oxide	2,000	Strontium oxide	100
Chromic oxide	900	Thorium dioxide	23,000
Ferric oxide	76,000	Titanium dioxide	4,300
Potassium oxide	32,000	Uranium oxide	3,000
Lithium oxide	24,000	Zinc oxide	100
Magnesium oxide	5,600	Zirconium dioxide	7,100
Manganese oxide	5,200	Others	3,900
Sodium oxide	51,000		
Neodymium oxide	900	***Total***	***630,000***

a. Sources: DIRS 103500-WVNS (n.d., WQR-1.1, Rev. 1, p. 7); DIRS 104413-Picha (1998, p. 3).
b. To convert kilograms to pounds, multiply by 2.2046.

Table A-38. Idaho National Engineering and Environmental Laboratory waste stream thermal output (watts).[a,b]

Output per waste canister	INTEC glass matrix	ANL-W ceramic matrix	ANL-W metal matrix
Average[c]	7.1	160	170
Worst case [d]	180	620	410

a. Source: DIRS 104406-Picha (1997, Attachment 1, p. 2).
b. INTEC = Idaho Nuclear Technology and Engineering Center; ANL-W = Argonne National Laboratory-West.
c. Based on average case; 2035 used as base year for Idaho Nuclear Technology and Engineering Center glass and 2000 for ANL-W matrices.
d. Based on worst case; 2020 used as base year for Idaho Nuclear Technology and Engineering Center glass and 2000 for ANL-W matrices.

Savannah River Site. The radionuclide inventories reported for the Savannah River Site high-level radioactive waste in Section A.2.3.5.2 were used to calculate projected heat generation rates for single canisters.

For the design-basis waste form, the heat generation rates 10 and 20 years after production are 465 and 302 watts per canister, respectively (DIRS 101909-Plodinec, Moore, and Marra 1993, pp. 8 and 9).

West Valley Demonstration Project. West Valley has calculated heat generation rates for a nominal West Valley canister after several different decay times (DIRS 103500-WVNS n.d., WQR-3.8, Rev. 5, 6/29/00, p. 3). In the nominal case, the ORIGEN2-computed heat generation rate was 239 watts at the calculational base time in 1988. The heat generation rate would decrease continuously from 239 watts to about 155 watts after 19 years of additional decay.

A.2.3.5.5 *Quantity of Waste Per Canister*

Table A-39 lists the estimated mass of glass per waste canister for each high-level radioactive waste stream.

Table A-39. Approximate mass of high-level radioactive waste glass per canister (kilograms).[a]

Waste stream[b]	Mass per canister	Source
Hanford	3,040	DIRS 104406-Picha (1997, Attachment 1, p. 2)
INEEL		
INTEC	1,560	DIRS 104406-Picha (1997, Attachment 1, p. 2)
ANL-W ceramic[c]	960 - 1,500	DIRS 104389-Goff (1998, Attachment, p. 5)
ANL-W metal[c]	1,500 - 4,850	DIRS 104389-Goff (1998, Attachment, p. 5)
Savannah River Site	2,000	DIRS 104403-Pearson (1998, all)
WVDP	2,000	DIRS 104406-Picha (1997, Attachment 1, p. 2)

a. To convert kilograms to pounds, multiply by 2.2046.
b. INEEL = Idaho National Engineering and Environmental Laboratory; INTEC = Idaho Nuclear technology and Engineering Center; ANL-W = Argonne National Laboratory-West; WVDP = West Valley Demonstration Project.
c. These values are estimates. ANL-W is evaluating waste package configurations compatible with existing storage and remote hot cell facilities. The geometries would be compatible with the Defense Waste Processing Facility high-level radioactive waste canister.

A.2.3.5.6 *High-Level Radioactive Waste Canister Parameters*

Hanford Site. Table A-40 lists preliminary physical parameters for a standard canister used for high-level radioactive wastes from the Hanford Site (DIRS 104406-Picha 1997, Table RL-3).

Idaho National Engineering and Environmental Laboratory. The Idaho Nuclear Technology and Engineering Center would use stainless-steel canisters identical in design to those used at the Savannah River Site in the Defense Waste Processing Facility. A similar canister would also be used to contain the ceramic and metal waste matrices resulting from the high-level radioactive waste processing at Argonne National Laboratory-West (DIRS 104406-Picha 1997, Table ID-1).

Savannah River Site. The fabrication specifications of the Defense Waste Processing Facility high-level radioactive waste canisters are described in detail in DIRS 101854-Marra, Harbour, and Plodinec (1995, all). The 3-meter (10-foot) long canisters are fabricated from four basic pieces of A240 304L austenitic stainless steel—the main cylinder, the bottom head, the top head, and a nozzle.

Table A-40. Parameters of the proposed standard canister for Hanford high-level radioactive waste disposal.[a]

Parameter	Value[b]	Comments[c]
Length	4.50 meters	1.5 meters longer than DWPF and WVDP canisters - nominal 4.5-meter length
Nominal outer diameter	0.61 meter	Same as DWPF and WVDP canisters
Material	304L stainless steel	Same as DWPF and WVDP canisters
Canister weight	720 kilograms	
Dished bottom	Yes	Same as DWPF and WVDP
Available volume	1.2 cubic meters	
Nominal percent fill	90 percent	Provides approximately same void volume as WVDP canister
Glass volume	1.1 cubic meters	

a. Source: DIRS 104406-Picha (1997, Table RL-3).
b. To convert meters to feet, multiply by 3.2808; to convert centimeters to inches, multiply by 0.3937; to convert kilograms to tons, multiply by 0.0011023; to convert cubic meters to cubic feet, multiply by 35.314.
c. DWPF = Defense Waste Processing Facility; WVDP = West Valley Demonstration Project.

West Valley Demonstration Project. The West Valley canister is designed, fabricated, and handled in accordance with the specifications in the West Valley Demonstration Project Waste Qualification Report (DIRS 103500-WVNS n.d., WQR-2.2). The West Valley canisters are also 3 meters (10 feet) long and fabricated from four principal 304L austenitic stainless-steel components.

A.2.3.5.7 *Nonstandard Packages*

Each site that would ship high-level radioactive waste to the repository has provided additional data on an estimate of nonstandard packages for possible inclusion in the candidate waste material. The mass, volume, and radioactivity of potential nonstandard packages would be dominated by failed or spent melters from the vitrification facilities. Final disposition plans for these melters are in development and vary from site to site. The EIS used the following assumptions to estimate the potential inventory.

Hanford Site. DOE could need to ship such nonstandard high-level radioactive waste packages as failed melters and failed contaminated high-level radioactive waste processing equipment to the repository. For this EIS, the estimated volume of nonstandard packages available for shipment to the repository from the Hanford Site would be equivalent to that described below for the Savannah River Site.

Idaho National Engineering and Environmental Laboratory. DOE proposes to treat and dispose of nonstandard packages under existing regulations. However, to bound the number of failed melters the Idaho National Engineering and Environmental Laboratory could ship to the repository, this EIS uses the same ratio of failed melters to the number of canisters produced as the Savannah River Site (DIRS 104401-Palmer 1997, p. 2). The Idaho National Engineering and Environmental Laboratory would produce approximately 20 percent of the number of canisters produced at the Savannah River Site, which assumes 10 failed melters. Therefore, the Idaho National Engineering and Environmental Laboratory assumes two failed melters. The volumes and other parameters would then be twice the values listed in Table A-41 for an individual melter.

Savannah River Site. Table A-41 lists the estimated parameters of nonstandard packages for repository shipment from the Savannah River Site.

West Valley Demonstration Project. The West Valley Demonstration Project anticipates that it would send only one melter to the repository at the end of the waste solidification campaign. It would be disposed of as a nonstandard package. Table A-42 lists the estimated parameters of nonstandard packages from the West Valley Demonstration Project.

Table A-41. Parameters of nonstandard packages from Savannah River Site.[a]

Parameter	Value
Volume	10 melters based on current planning to 2021
Activity	4.5 equivalent DWPF[b] canisters for each melter
Mass	1,000 metric tons[c] for 10 melters (filled melter: 100 metric tons)
Chemical composition	Glass (see Section A.2.3.5.3) Melter – Refractory brick Aluminum Stainless steel Inconel
Quantity per disposal package	1 melter per disposal package
Thermal generation	4.5 times the heat generation of a single canister for each melter

a. Source: DIRS 104402-Pearson (1997, Attachment 1, pp. 3 and 4).
b. DWPF = Defense Waste Processing Facility.
c. To convert metric tons to tons, multiply by 1.1023.

Table A-42. Parameters of nonstandard packages from West Valley Demonstration Project.[a]

Parameter	Value[b]
Volume	1 melter (24 cubic meters)
Activity	1.1 equivalent West Valley canisters
Mass	52 metric tons
Chemical composition	Melter refractories (38 metric tons) Inconel (11 metric tons) Stainless steel (1.6 metric tons) Glass (see Table A-37)
Quantity per disposal package	1 melter per package
Thermal generator	1.1 times the heat generation of a single canister (see Section A.2.3.5.4)

a. Source: DIRS 104418-Rowland (1997, all).
b. To convert cubic meters to cubic feet, multiply by 35.314; to convert metric tons to tons, multiply by 1.1023.

A.2.4 SURPLUS WEAPONS-USABLE PLUTONIUM

A.2.4.1 Background

The President has declared an amount of weapons-usable plutonium to be surplus to national security needs (DIRS 118979-DOE 1999, p. 1-1). This material includes the following:

- Plutonium in various forms (metal, oxide, etc.)
- Nuclear weapons components
- Materials that DOE could process in the future to produce purified plutonium
- Plutonium residues that DOE previously saved for future recovery of purified plutonium

These materials are currently stored at various facilities throughout the United States. DOE would draw the specific surplus weapons-usable plutonium it ultimately disposed of from the larger inventory primarily stored at these sites.

DOE could process the surplus weapons-usable plutonium as two material streams. One stream would be an immobilized plutonium ceramic form that DOE would dispose of using a can-in-canister technique with high-level radioactive waste. The second stream would be mixed uranium and plutonium oxide fuel assemblies that would be used for power production in light-water reactors and disposed of as commercial spent nuclear fuel. The Surplus Plutonium Disposition Final Environmental Impact

Statement (DIRS 118979-DOE 1999, p. 1-1) evaluates the quantity of plutonium processed in each stream. This EIS assumes that approximately one-third of the surplus weapons-usable plutonium would be immobilized and two-thirds would be made into mixed-oxide commercial nuclear fuel. The actual split could include the immobilization of up to the entire inventory of plutonium addressed in DIRS 118979-DOE (1999, p. 1-1).

A.2.4.2 Sources

DOE would produce the immobilized plutonium and/or mixed-oxide fuel at the Savannah River Site as determined in a Record of Decision for the Surplus Plutonium Disposition Final Environmental Impact Statement (65 *FR* 1608; January 11, 2000). The Department analyzed the potential environmental impacts of using mixed-oxide fuel in six commercial light-water reactors in which it proposes to irradiate the mixed-oxide fuel: both units at Catawba in South Carolina; both units at McGuire in North Carolina; and both units at North Anna Power Station in Virginia (65 *FR* 1608, January 11, 2000). Subsequently, the Department has decided to pursue irradiation of mixed-oxide fuel at only the Catawba and McGuire units.

A.2.4.3 Present Storage and Generation Status

DOE suspended planning and work activities for the immobilized plutonium program in April 2001. For planning purposes, immobilized plutonium production could start in 2012. DOE has not determined an immobilized plutonium production completion date.

The immobilization of one-third of the plutonium would produce an estimated 101 additional canisters of high-level radioactive waste, which the production location would store until shipment to the repository. The immobilization of the full considered inventory of plutonium would produce an estimated 272 additional canisters of high-level radioactive waste. This EIS assumes that the production location would be the Savannah River Site and, therefore, used the physical dimensions of the Defense Waste Processing Facility canisters to calculate these values (DIRS 118979-DOE 1999, pp. 2-26 and 2-27).

Commercial light-water reactors would use mixed-oxide fuel assemblies for power production starting as early as 2007. This fuel would replace the low-enriched uranium fuel that normally would be in the reactors. After the fuel assemblies were discharged from the reactors as spent mixed-oxide fuel, the reactor sites would store them until shipment to the repository.

A.2.4.4 Final Waste Form

The final waste form would be immobilized plutonium or spent mixed-oxide fuel. Section A.2.4.5 discusses the characteristics of these materials. The spent mixed-oxide fuel discussed here has different characteristics than the mixed-oxide fuel included in the National Spent Fuel Program (DIRS 153072-Wheatley 2000, all) and described in Section A.2.2.

A.2.4.5 Material Characteristics

A.2.4.5.1 *Mixed-Oxide Fuel*

A.2.4.5.1.1 Mass and Volume. The EIS on surplus weapons-usable plutonium disposition (DIRS 118979-DOE 1999, p. 1-9) evaluates the disposal of two-thirds of the plutonium as mixed-oxide fuel. The amount of plutonium and uranium measured in metric tons of heavy metal going to a repository would depend on the average percentage of plutonium in the fuel. The percentage of plutonium would be influenced by the fuel design. DOE has chosen pressurized-water reactors for the proposed irradiation of these assemblies. For pressurized-water reactors, the expected average plutonium percentages would be approximately 4.6 percent; however, they could range between 3.5 and 6 percent (DIRS 104422-Stevenson 1997, pp. 5 and 6). Table A-43 lists estimates and ranges for the total metric tons of heavy metal (uranium and plutonium) that would result from disposing of two-thirds of the plutonium in mixed-oxide fuel. The table also lists a corresponding estimate for the number of assemblies required, based on using the typical assemblies described in Section A.2.1.4. The ranges of metric tons of heavy metal account for the proposed range in potential plutonium percentage.

Table A-43. Estimated spent nuclear fuel quantities for disposition of two-thirds of the surplus weapons-usable plutonium in mixed-oxide fuel.[a,b]

Reactor and fuel type	Plutonium percentage	Best estimate (MTHM)	Assemblies required	Range (MTHM)
Pressurized-water reactor	4.56	700	1,500	500-900

a. Source: DIRS 104422-Stevenson (1997, pp. 5 and 6).
b. MTHM = metric tons of heavy metal; to convert metric tons to tons, multiply by 1.1023.

DOE assumed that each spent mixed-oxide assembly irradiated and disposed of would replace an energy-equivalent, low-enriched uranium assembly originally intended for the repository. The mixed-oxide assemblies would be part of the 63,000 metric tons (69,000 tons) that comprise the commercial spent nuclear fuel disposal amount in the Proposed Action (DIRS 104405-Person 1998, all). DOE also assumes that the average burnup levels for the pressurized-water reactor would be the same as that for the energy-equivalent, low-enriched uranium fuel. Table A-44 lists the assumed burnup levels and the amount of heavy metal in an assembly.

Table A-44. Assumed design parameters for typical mixed-oxide assembly.[a]

Parameter	Pressurized-water reactor
Mixed-oxide and low-enriched uranium burnup (MWd/MTHM)[b]	45,000
Mixed-oxide assembly mass (kilograms[c] of heavy metal)	450
Mixed-oxide assembly percentage of plutonium	4.56

a. Source: DIRS 104422-Stevenson (1997, p. 7).
b. MWd/MTHM = megawatt days per metric ton of heavy metal; to convert metric tons to tons, multiply by 1.1023.
c. To convert kilograms to pounds, multiply by 2.2046.

The analysis assumed that the mixed-oxide spent nuclear fuel would replace the low-enriched uranium fuel. Because of the similarities in the two fuel types, impacts to the repository would be small. Nuclear criticality, radionuclide release rates, and heat generation comparisons are evaluated in DIRS 104422-Stevenson (1997, pp. 35 to 37).

A.2.4.5.1.2 Amount and Nature of Radioactivity. Tables A-45 and A-46 list isotopic composition data for spent mixed-oxide fuel assemblies. The tables reflect SCALE data files from an Oak Ridge National Laboratory report used with computer simulation to project the characteristics of spent mixed-oxide fuel in pressurized-water reactors (DIRS 100976-Murphy 1997, Volume 3, Appendix B). The tables summarize data for two different potential fuel assemblies: a typical pressurized-water reactor, and a high-burnup pressurized-water reactor. A high burnup pressurized-water assembly would be irradiated for three cycles in comparison to the two cycles for the typical assemblies. For each of these assemblies, the tables provide radioactivity data for the common set of nuclides used in this EIS for the assumed 5-year minimum cooling time.

A.2.4.5.1.3 Chemical Composition. Tables A-47 and A-48 list the elemental distributions for the typical and high-burnup pressurized-water reactor spent mixed-oxide fuel assemblies.

A.2.4.5.1.4 Thermal Output. Table A-49 lists the decay heat from the representative mixed-oxide spent fuel assemblies at a range of times after discharge.

Table A-45. Radionuclide activity for typical pressurized-water reactor spent mixed-oxide assembly.[a]

Radionuclide[b]	Curies per assembly	Radionuclide[b]	Curies per assembly
Hydrogen-3	2.0×10^{2}	Samarium-151	5.3×10^{2}
Carbon-14	3.4×10^{-1}	Uranium-234	4.9×10^{-2}
Cobalt-60	1.7×10^{3}	Uranium-235	1.0×10^{-3}
Nickel-59	1.1	Uranium-236	6.4×10^{-3}
Nickel-63	1.4×10^{2}	Uranium-238	1.4×10^{-1}
Krypton-85	1.9×10^{3}	Plutonium-238	1.2×10^{3}
Strontium-90	1.7×10^{4}	Plutonium-239	6.6×10^{2}
Zirconium-93	6.5×10^{-2}	Plutonium-240	8.6×10^{2}
Niobium-93m	2.8×10^{1}	Plutonium-241	2.0×10^{5}
Niobium-94	6.8×10^{-1}	Americium-241	2.2×10^{3}
Technetium-99	6.3	Americium-242/242m	3.4×10^{1}
Ruthenium-106	1.6×10^{4}	Americium-243	2.4×10^{1}
Iodine-129	2.1×10^{-2}	Curium-242	6.0×10^{1}
Cesium-134	1.4×10^{4}	Curium-243	3.2×10^{1}
Cesium-137	4.7×10^{4}	Curium-244	2.6×10^{3}

a. Source: DIRS 100976-Murphy (1997, Appendix B).
b. Half-lives are listed in Table A-11.

Table A-46. Radionuclide activity for high-burnup pressurized-water reactor spent mixed-oxide assembly.[a, b]

Radionuclide[b]	Curies per assembly	Radionuclide[b]	Curies per assembly
Hydrogen-3	2.9×10^{2}	Uranium-234	6.8×10^{-2}
Carbon-14	5.4×10^{-1}	Uranium-235	6.7×10^{-4}
Cobalt-60	2.4×10^{3}	Uranium-236	7.7×10^{-3}
Nickel-59	1.7	Uranium-238	1.5×10^{-1}
Nickel-63	2.3×10^{2}	Plutonium-238	2.7×10^{3}
Krypton-85	2.6×10^{3}	Plutonium-239	4.6×10^{2}
Strontium-90	2.4×10^{4}	Plutonium-240	8.8×10^{2}
Niobium-93m	3.9×10^{1}	Plutonium-241	2.2×10^{5}
Niobium-94	9.8×10^{-1}	Americium-241	2.5×10^{3}
Technetium-99	9.0	Americium-242/242m	4.9×10^{1}
Ruthenium-106	1.8×10^{4}	Americium-243	5.6×10^{1}
Iodine-129	3.0×10^{-2}	Curium-242	1.0×10^{2}
Cesium-134	2.5×10^{4}	Curium-243	8.5×10^{1}
Cesium-137	7.0×10^{4}	Curium-244	8.9×10^{3}
Samarium-151	5.4×10^{2}		

a. Sources: DIRS 100976-Murphy (1997, Volume 3, Appendix B).
b. Half-lives are listed in Table A-11.

A.2.4.5.1.5 Physical Parameters. Because the mixed-oxide fuel would replace low-enriched uranium fuel in existing reactors, Section A.2.1.5.5 describes the physical parameters, with the exception of uranium and plutonium content, which are listed in Table A-44.

A.2.4.5.2 *Immobilized Plutonium*

DOE has not yet determined the total quantity of plutonium for immobilization. The Department assumes that two-thirds of the considered inventory is "clean" metal suitable for use in mixed-oxide fuel, and that it could dispose of this material by burning it in reactors (DIRS 118979-DOE 1999, p. 1-1). The remaining surplus plutonium would require considerable additional chemical processing to make it suitable for reactor use. This EIS evaluates two cases, one in which DOE immobilizes only the "impure" materials (base case) and a second in which it immobilizes the entire considered surplus inventory. The base case is evaluated for the Proposed Action because it is DOE's preferred alternative (DIRS 118979-

Table A-47. Elemental distribution of typical burn-up pressurized-water reactor spent mixed-oxide assembly.[a]

Element	Grams per assembly[b]	Percent[c]	Element	Grams per assembly	Percent
Americium	770	0.12	Palladium	1,200	0.19
Barium	750	0.12	Phosphorus	140	0.02
Carbon	67	0.01	Plutonium	17,000	2.59
Cerium	1,100	0.16	Praseodymium	500	0.08
Cesium	1,500	0.23	Rhodium	360	0.05
Chromium	2,300	0.36	Rubidium	91	0.01
Europium	90	0.01	Ruthenium	1,300	0.20
Iodine	150	0.02	Samarium	440	0.07
Iron	4,600	0.71	Silicon	66	0.01
Krypton	100	0.02	Strontium	210	0.03
Lanthanum	540	0.08	Technetium	370	0.06
Manganese	110	0.02	Tellurium	260	0.04
Molybdenum	1,700	0.27	Tin	1900	0.28
Neodymium	1,700	0.26	Uranium	428,000	65.92
Neptunium	72	0.01	Xenon	2500	0.38
Nickel	4,400	0.68	Yttrium	110	0.02
Niobium	330	0.05	Zirconium	111,000	17.10
Oxygen	62,000	9.56	***Totals***	***648,000***	***99.73***

a. Source: DIRS 104399-Murphy (1998, all).
b. To convert grams to ounces, multiply by 0.035274.
c. Table includes only elements that constitute at least 0.01 percent of the total; therefore, total is slightly less than 100 percent.

Table A-48. Elemental distribution of high burn-up pressurized-water reactor spent mixed-oxide assembly.[a]

Element	Grams per assembly[b]	Percent[c]	Element	Grams per assembly	Percent
Americium	1,000	0.16	Palladium	2,000	0.30
Barium	1,200	0.18	Phosphorus	140	0.02
Carbon	70	0.01	Plutonium	14,000	2.22
Cerium	1,600	0.24	Praseodymium	750	0.11
Cesium	2,100	0.33	Rhodium	460	0.07
Chromium	2,300	0.36	Rubidium	140	0.02
Europium	140	0.02	Ruthenium	2,000	0.31
Iodine	220	0.03	Samarium	630	0.10
Iron	4,600	0.71	Silicon	66	0.01
Krypton	150	0.02	Strontium	300	0.05
Lanthanum	810	0.12	Technetium	520	0.08
Manganese	100	0.02	Tellurium	390	0.06
Molybdenum	2,500	0.39	Tin	1,900	0.29
Neodymium	2,500	0.39	Uranium	421,000	64.84
Neptunium	93	0.01	Xenon	3,700	0.57
Nickel	4,400	0.68	Yttrium	170	0.03
Niobium	330	0.05	Zirconium	111,000	17.10
Oxygen	62,000	9.56	***Totals***	***646,000***	***99.46***

a. Source: DIRS 104399-Murphy (1998, all).
b. To convert grams to ounces, multiply by 0.035274.
c. Table includes only elements that constitute at least 0.01 percent of the total; therefore, total is slightly less than 100 percent.

DOE 1999, p. 1-1). The EIS evaluates the second case for potential cumulative impacts (Modules 1 and 2) because it would conservatively predict the largest number of required high-level radioactive waste canisters.

Table A-49. Mixed-oxide spent nuclear fuel thermal profile (watts per assembly).[a]

Years	Typical PWR[b]	High-burnup PWR
1	6,100	8,000
5	1,000	1,600
10	670	1,100
15	610	970
30	540	780
100	370	430
300	240	260
1,000	110	110
3,000	42	38
10,000	25	22
30,000	10	7.9
100,000	1.5	1.3
250,000	0.5	0.6

a. Source: DIRS 100976-Murphy (1997, Volume 3, Appendix B).
b. PWR = pressurized-water reactor.

A.2.4.5.2.1 Mass and Volume. In DOE's preferred disposition alternative, immobilized plutonium would arrive at the repository in canisters of vitrified high-level radioactive waste that would be externally identical to standard canisters from the Defense Waste Processing Facility at the Savannah River Site. Smaller cans containing immobilized plutonium in ceramic disks would be embedded in each canister of high-level radioactive waste glass. This is the *can-in-canister* concept. Because the design of the can-in-canister is not final, DOE has not determined final waste loadings per canister, volume displaced by the cans, or other specifications. DOE estimates that each canister would contain 28 cans, but has not yet finalized the actual number. One of the limitations on the number of cans is determined by the ability to ensure that the high-level radioactive waste glass would fill completely around the cans; increasing the volume that the cans would occupy in a canister could increase the difficulty of achieving this.

Marra, Harbour, and Plodinec (DIRS 101854-1995, p. 2) describes the volume of a high-level radioactive waste canister. Each canister has a design capacity of 2,000 kilograms (4,400 pounds) of high-level radioactive waste glass. A nominal glass density of 2.7 grams per cubic centimeter (0.10 pound per cubic inch) yields a design glass volume of 620 liters (22 cubic feet). The 28 cans containing plutonium would displace 68 liters (2.4 cubic feet), or about 11 percent of the available volume. The rack holding the cans would displace about an additional 1 percent of the available volume, yielding a total displacement of about 12 percent.

Table A-50 lists the number of high-level radioactive waste canisters required to dispose of immobilized surplus plutonium using the loading and volumetric assumptions given above for both the base and full inventory cases. It also lists the number of additional canisters DOE would have to produce (in addition to those the high-level radioactive waste producer would already have produced) due to the displacement of high-level radioactive waste glass by the plutonium-containing canisters. The total number of required canisters would be a function of both the number of cans in each canister and the plutonium loading of the immobilization form. The number of additional canisters would depend only on the plutonium loading of the immobilization form.

A.2.4.5.2.2 Amount and Nature of Radioactivity. Assuming the current 10.5-percent plutonium loading in the ceramic, the expected isotopic composition of the various materials in the feedstream for ceramic production, and the nominal quantity of ceramic in each canister, Stevenson (DIRS 104422-1997, p. 49) calculated the activity of the immobilized material in each high-level radioactive waste canister.

Table A-50. Number of canisters required for immobilized plutonium disposition.[a,b]

Canisters	Base case	Full inventory case
Containing plutonium	670	1,820
In excess of those required for DWPF[c] (12% of total canisters)	101	272
Additional[d]	1.7%	4.5%

a. Source: DIRS 118979-DOE (1999, p. 2-29).
b. Assumes displacement of 12 percent of the high-level radioactive waste glass by plutonium cans and rack.
c. DWPF = Defense Waste Processing Facility.
d. As percentage of total planned DWPF canisters (about 6,000).

The figures do not include the radioactivity of the vitrified high-level radioactive waste that would surround the cans of immobilized plutonium. Calculation of the total radioactivity of a canister requires the subtraction of approximately 12 percent from the radioactivity of a full high-level radioactive waste canister to account for the displacement of the immobilized plutonium and its rack. Those reduced numbers, added to the appropriate figures in Table A-51, produce the total activity of a plutonium-containing high-level radioactive waste canister.

Table A-51. Average total radioactivity of immobilized plutonium ceramic in a single canister in 2010 (curies).[a,b]

Radionuclide[c]	Base case	Full inventory
Plutonium-238	120	60
Plutonium-239	1,600	1,700
Plutonium-240	550	430
Plutonium-241	4,700	2,800
Plutonium-242	0.098	0.046
Americium-241	720	430
Uranium-234	< 0.000015[d]	< 0.000005
Uranium-235	0.0024	< 0.0011
Uranium-238	0.019	0.019
Thorium-232	< 0.00003	< 0.00003
Totals	***7,700***	***5,400***

a. Source: DIRS 104422-Stevenson (1997, p. 49).
b. Assumes 10.5 percent of plutonium by weight in ceramic form and 1:2 molar ratio of plutonium to uranium. These values account only for the radioactivity in the immobilized form; they do not include that in the surrounding high-level radioactive waste glass.
c. Half-lives are listed in Table A-11.
d. < = less than.

Values for the base case and the full inventory case are different because the plutonium in the base case contains more transuranic radionuclides, other than plutonium-239, than does the remainder of the plutonium. Thus, the “other” transuranic radionuclides are diluted in the full inventory case. From a thermal output and radiological impact standpoint, the base case is a more severe condition and, therefore, DOE has used it for the Proposed Action analysis.

Section A.2.3.5.2 contains information on the radioactivity contained in a standard Defense Waste Processing Facility high-level radioactive waste canister.

A.2.4.5.2.3 Chemical Composition. The current design for a ceramic immobilization form is a multiphase titanate ceramic, with a target bulk composition listed in Table A-52. The neutron absorbers, hafnium and gadolinium, are each present at a 1-to-1 atomic ratio to plutonium, and the atomic ratio of uranium to plutonium is approximately 2-to-1. For the base case, the presence of impurities in some categories of surplus weapons-usable plutonium would result in the presence of a few weight percent of other nonradioactive oxides in some of the actual ceramic; Table A-52 does not list these impurities (DIRS 104422-Stevenson 1997, p. 51).

Table A-52. Chemical composition of baseline ceramic immobilization form.[a]

Oxide	Approximate percent by weight
Titanium oxide	36
Hafnium oxide	10
Calcium oxide	10
Gadolinium oxide	8
Plutonium oxide	12
Uranium oxide	24

a. Source: DIRS 104422-Stevenson (1997, p. 51).

The ceramic phase assemblage is mostly Hf-pyrochlore [(CaGd)(Gd,Pu,U,Hf)Ti_2O_7], with subsidiary Hf-zirconolite [(CaGd)(Gd,Pu,U,Hf)Ti_2O_7)], and minor amounts of brannerite [(U,Pu,Gd)Ti_2O_6] and rutile [(Ti,Hf)O_2]. Pyrochlore and zirconolite differ in their crystalline structures. The presence of silicon as an impurity in the plutonium could lead to the formation of a minor amount of a silicate glass phase in the ceramic. This phase could contain a trace amount of the immobilized plutonium. Some residual plutonium oxide (less than 0.5 percent of the total quantity of plutonium) could also be present. The residual plutonium oxide contains uranium with smaller amounts of gadolinium and hafnium as a result of partial reaction with the other constituents of the ceramic (DIRS 104422-Stevenson 1997, p. 51). Section A.2.3.5.3 describes the chemical composition of the high-level radioactive waste glass surrounding the plutonium-containing cans.

A.2.4.5.2.4 Thermal Output. DIRS 104422-Stevenson (1997, p. 49) has presented the heat generation of the immobilized ceramic. These figures represent only the heat from the ceramic; they do not account for the heat from the surrounding high-level radioactive waste glass. The total heat from a Defense Waste Processing Facility canister containing high-level radioactive waste and immobilized plutonium would be the value listed in Table A-53 combined with 88 percent of the value listed in Section A.2.3.5.4 for the heat from a Defense Waste Processing Facility canister.

Table A-53. Thermal generation from immobilized plutonium ceramic in a single canister in 2010 (watts per canister).[a]

Case	Thermal production
Base case	8.6
Full inventory case	7.0

a. Source: DIRS 104422-Stevenson (1997, p. 49).
b. To convert metric tons to tons, multiply by 1.1023.

A.2.5 COMMERCIAL GREATER-THAN-CLASS-C LOW-LEVEL WASTE

A.2.5.1 Background

Title 10 of the Code of Federal Regulations, Part 61 (10 CFR Part 61), establishes disposal requirements for three classes of waste—A, B, and C—suitable for near-surface disposal. Class C has the highest level of radioactivity and therefore the most rigorous disposal specifications. Wastes with concentrations above Class C limits (listed in 10 CFR 61.55 Tables 1 and 2 for long and short half-life radionuclides, respectively) are called Greater-Than-Class-C low-level waste, and are not generally suitable for near-surface disposal (DIRS 101798-DOE 1994, all).

Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate waste that exceeds the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. Public Law 99-240 assigns the Federal Government, specifically DOE, the responsibility for disposing of this Greater-Than-Class-C waste. DOE could use a number of techniques for the disposal of these wastes, including engineered near-surface disposal, deep borehole disposal, intermediate-depth burial, and disposal in a deep geologic repository (DIRS 101798-DOE 1994, all).

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type (DIRS 101798-DOE 1994, all).

Greater-Than-Class-C waste could include the following materials:

- Nuclear powerplant operating wastes
- Nuclear powerplant decommissioning wastes
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE-held Greater-Than-Class-C waste (addressed in Section A.2.6)
- Greater-Than-Class-C waste from other generators

This section describes the quantities and characteristics of these waste types.

A.2.5.2 Sources

Sources or categories of Greater-Than-Class-C waste include:

- DOE facilities (addressed in Section A.2.6)
- Nuclear utilities
- Sealed sources
- Other generators

Nuclear utility waste includes activated metals and process wastes from commercial nuclear powerplants. Sealed sources are radioactive materials in small metallic capsules used in measurement and calibration devices. Other generator wastes consist of sludge, activated metals, and other wastes from radionuclide manufacturers, commercial research, sealed-source manufacturers, and similar operations. The decommissioning of light-water reactors probably will generate additional Greater-Than-Class-C waste. Some internal reactor components will exceed Class C disposal limits.

A.2.5.3 Present Status

Nuclear utilities store their Greater-Than-Class-C waste at the generator site, where it will remain until a disposal option becomes available.

Sealed sources are held by a Nuclear Regulatory Commission or Agreement State licensee. Current DOE sealed-source management plans call for the licensees to store their sealed-source wastes until a disposal option becomes available. If storage by a licensee became physically or financially impossible and a threat to public health and safety, the Nuclear Regulatory Commission would determine if the source was a candidate for DOE storage. At that time, the Commission could request that DOE accept the source for storage, reuse, or recycling. The inventory projections do not include such a transfer of material.

In 1993, there were 13 identified "other generators" of Greater-Than-Class-C waste (DIRS 101798-DOE 1994, Appendix D), which were categorized into seven business types:

- Carbon-14 user
- Industrial research and development
- Irradiation laboratory
- Fuel fabricator
- University reactor
- Sealed-source manufacturer
- Nonmedical academic institution

These generators store their wastes at their sites and will continue to do so until a disposal site becomes operational.

A.2.5.4 Final Waste Form

The final disposition method for Greater-Than-Class-C waste is not known. If DOE was to place such waste in a repository, it is assumed that it would be placed in a disposal canister before shipment. The EIS assumes the use of a canister similar to the naval canister, which is described in Section A.2.2.5.6, for all shipments by rail and a package similar to the high-level radioactive waste canisters for all shipments by truck.

A.2.5.5 Waste Characteristics

Table A-54 lists existing and projected volumes for the three Greater-Than-Class-C waste generator sources. DOE conservatively projects the volume of nuclear utility wastes to 2055 because that date would include the majority of this waste from the decontamination and decommissioning of commercial nuclear reactors. The projected volumes conservatively reflect the highest potential volume and activity based on inventories, surveys, and industry production rates. DOE projects the other two generator sources (sealed sources and other generators) to 2035 (DIRS 101798-DOE 1994, all).

Table A-54. Greater-Than-Class-C waste volume by generator source (cubic meters).[a,b]

Source	1993 volume	Projected volume
Nuclear electric utility	26	1,300
Sealed sources	39	240
Other generators	74	470
Totals	***139***	***2,010***

a. Source: DIRS 101798-DOE (1994, all).
b. To convert cubic meters to cubic feet, multiply by 35.314.

The data concerning the volumes and projections are from Greater-Than-Class-C Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics (DIRS 101798-DOE 1994, Appendix A-1), which provides detailed radioactivity reports for such waste currently stored at nuclear utilities. Table A-55 summarizes the radioactivity data for the primary radionuclides in the waste, projected to 2055.

Table A-55. Commercial Greater-Than-Class-C waste radioactivity (curies) by nuclide (projected to 2055).[a]

Nuclide[b]	Radioactivity
Carbon-14	6.8×10^4
Cobalt-60	3.3×10^7
Iron-55	1.8×10^7
Hydrogen-3	1.2×10^4
Manganese-54	3.2×10^4
Niobium-94	9.8×10^2
Nickel-59	2.5×10^5
Nickel-63	3.7×10^7
Transuranics	2.0×10^3
Total	$\boldsymbol{8.8 \times 10^7}$

a. Source: DIRS 101798-DOE (1994, Appendix A-1).
b. Half-lives are listed in Table A-11.

Appendix B of DIRS 101798-DOE (1994) provides detailed radioactivity reports for the sealed sources, which could be candidate wastes for the repository. Table A-56 summarizes the radioactivity data for the radionuclides in these sources, projected to 2035.

Table A-56. Sealed-source Greater-Than-Class-C waste radioactivity (curies) by nuclide (projected to 2035).[a]

Nuclide[b]	Radioactivity
Americium-241	8.0×10^4
Curium-244	1.6×10^2
Cesium-137	4.0×10^7
Plutonium-238	1.6×10^4
Plutonium-239	1.1×10^5
Plutonium-241	2.8×10^1
Technetium-99	5.8×10^3
Uranium-238	5.7×10^1
Total	$\boldsymbol{4.2 \times 10^7}$

a. Source: DIRS 101798-DOE (1994, Appendix A-1).
b. Half-lives are listed in Table A-11.

DIRS 101798-DOE (1994, Section 5) also identifies the 13 other generators and the current and projected volumes and total radioactivity of Greater-Than-Class-C waste held by each. It does not provide specific radionuclide activity by nuclide. DOE used the data to derive a distribution, by user business type, of the specific nuclides that comprise the total radioactivity. Table A-57 lists this distributed radioactivity for other generators.

A detailed chemical composition by weight percentage for current Greater-Than-Class-C waste is not available. However, Table A-58 lists the typical composition of such wastes by generator.

The heat generation rates or thermal profiles for this waste type are not included in the source documentation. However, the contribution to the total thermal load at the repository from the Greater-Than-Class-C radioactive waste would be very small in comparison to commercial spent nuclear fuel or high-level radioactive waste.

Table A-57. Other generator Greater-Than-Class-C waste radioactivity (in curies) by nuclide (projected to 2035).[a]

Nuclide[b]	Radioactivity
Carbon-14	7.7×10^{3}
Transuranic	2.2×10^{3}
Cobalt-60	1.5×10^{2}
Nickel-63	1.5×10^{2}
Americium-241	2.4×10^{3}
Cesium-137	6.6×10^{1}
Technetium-99	5.1×10^{-2}
Total[c]	$\boldsymbol{1.3 \times 10^{4}}$

a. Source: Derived from DIRS 101798-DOE (1994, Appendix D).
b. Half-lives are listed in Table A-11.
c. Total differs from sum of values due to rounding.

Table A-58. Typical chemical composition of Greater-Than-Class-C wastes.[a]

Source	Typical composition
Nuclear electric utility	Stainless steel-304, and zirconium alloys
Sealed sources	Stainless steel-304 (source material has very small mass contribution)
Other generators	Various materials

a. Source: DIRS 101798-DOE (1994, all).

A.2.6 SPECIAL-PERFORMANCE-ASSESSMENT-REQUIRED LOW-LEVEL WASTE

A.2.6.1 Background

DOE production reactors, research reactors, reprocessing facilities, and research and development activities generate wastes that exceed the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. The Department is responsible for the safe disposal of such waste, and could use a number of techniques such as engineered near-surface disposal, deep borehole disposal, intermediate-depth burial, or disposal in a deep geologic repository. These wastes have been designated as Special-Performance-Assessment Required wastes.

DOE Special-Performance-Assessment-Required waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

A.2.6.2 Sources

DOE has identified Special-Performance-Assessment-Required waste inventories at several locations. Table A-59 lists the generators and amounts of these wastes. These amounts include current and projected inventories. These inventories are subject to revision as DOE develops its site material management programs and facility decommissioning plans.

Table A-59. Estimated Special-Performance-Assessment-Required low-level waste volume and mass by generator source.[a]

Source[b]	Volume (cubic meters)[c]	Mass (kilograms)[d]
Hanford	20	360,000
INEEL[e]	20	280,000
ORNL	2,900	4,700,000
WVDP	550	5,200,000
ANL-E	1	230
Naval Reactors Facility at INEEL	500	2,500,000
Totals (rounded)	***3,990***	***13,000,000***

a. Source: DIRS 104411-Picha (1998, all).
b. INEEL = Idaho National Engineering and Environmental Laboratory (including Argonne National Laboratory-West); ORNL = Oak Ridge National Laboratory; WVDP = West Valley Demonstration Project; ANL-E = Argonne National Laboratory-East.
c. To convert cubic meters to cubic yards, multiply by 1.3079.
d. To convert kilograms to pounds, multiply by 2.2046.
e. Includes Argonne National Laboratory-West.

A.2.6.3 Present Status

DOE stores its Special-Performance-Assessment-Required waste at the generator sites listed in Table A-59. Tables A-60 through A-63 list the waste inventories at the individual sites. For radionuclides, these tables include only the reported isotopes with inventories greater than 1×10^{-5} curies. Table A-64 lists the chemical composition of this material at each site.

Table A-60. Hanford Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide[b]	Radioactivity
Cesium-137	6.0×10^{4}
Strontium-90	6.0×10^{4}

a. Source: DIRS 104411-Picha (1998, all).
b. Half-lives are listed in Table A-11.

Table A-61. Idaho National Engineering and Environmental Laboratory (including Argonne National Laboratory-West) Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide[b]	Radioactivity
Hydrogen-3	5.9×10^{6}
Carbon-14	8.3×10^{2}
Cobalt-60	1.1×10^{6}
Nickel-59	9.0×10^{1}
Nickel-63	1.3×10^{4}
Strontium-90	7.4×10^{3}
Niobium-94	1.4×10^{2}
Technetium-99	3.3
Cesium-137	3.1×10^{1}
Radium-226	3.0×10^{1}
Plutonium-239	2.0×10^{1}
Americium-241	2.4×10^{2}

a. Source: DIRS 104411-Picha (1998, all).
b. Half-lives are listed in Table A-11.

Table A-62. Oak Ridge National Laboratory Special-Performance-Assessment-Required low-level waste radioactivity by nuclide (curies).[a]

Nuclide[b]	Radioactivity
Hydrogen-3	1.9×10^{6}
Carbon-14	1.0×10^{1}
Cobalt-60	1.9×10^{6}
Nickel-59	7.6×10^{3}
Nickel-63	7.5×10^{5}
Strontium-90	8.3×10^{7}
Niobium-94	1.0×10^{4}
Technetium-99	8.0×10^{-1}
Iodine-129	7.5×10^{-5}
Cesium-137	1.7×10^{-4}

a. Source: DIRS 104411-Picha (1998, all).
b. Half-lives are listed in Table A-11.

Table A-63. Radioactivity of naval Special-Performance-Assessment-Required waste (curies per package).[a]

Radionuclide[b]	Short canister	Long canister	Radionuclide	Short canister	Long canister
Americium-241	5.4×10^{-2}	6.0×10^{-2}	Nickel-59	2.2×10^{2}	2.5×10^{2}
Americium-242m	5.8×10^{-4}	6.5×10^{-4}	Nickel-63	2.7×10^{4}	3.0×10^{4}
Americium-243	5.8×10^{-4}	6.5×10^{-4}	Plutonium-239	2.1×10^{-2}	2.4×10^{-2}
Carbon-14	3.2	3.6	Plutonium-240	5.4×10^{-3}	6.0×10^{-3}
Chlorine-36	5.3×10^{-2}	6.0×10^{-2}	Plutonium-241	4.1	4.6
Curium-242	1.4×10^{-3}	1.5×10^{-3}	Plutonium-242	4.5×10^{-5}	5.1×10^{-5}
Curium-243	6.6×10^{-4}	7.4×10^{-4}	Ruthenium-106	2.1×10^{-1}	2.3×10^{-1}
Curium-244	7.0×10^{-2}	7.9×10^{-2}	Selenium-79	1.2×10^{-5}	1.3×10^{-5}
Curium-245	1.3×10^{-5}	1.5×10^{-5}	Samarium-151	1.7×10^{-2}	1.9×10^{-2}
Cesium-134	1.6	1.8	Tin-126	1.2×10^{-5}	1.3×10^{-5}
Cesium-135	1.1×10^{-5}	1.2×10^{-5}	Strontium-90	4.2×10^{-1}	4.7×10^{-1}
Cesium-137	1.1	1.3	Technetium-99	5.3×10^{-4}	6.0×10^{-4}
Hydrogen-3	1.5	1.7	Uranium-232	1.2×10^{-4}	1.4×10^{-4}
Krypton-85	4.9×10^{-2}	5.6×10^{-2}	Uranium-233	7.8×10^{-5}	8.8×10^{-5}
Niobium-93m	3.6×10^{-1}	4.1×10^{-1}	Zirconium-93	3.8×10^{-1}	4.3×10^{-1}
Niobium-94	5.9×10^{-1}	6.7×10^{-1}			

a. Source: DIRS 124679-Beckett (1998, Attachment 1).
b. Half-lives are listed in Table A-11.

Table A-64. Typical chemical composition of Special-Performance-Assessment-Required low-level waste.[a]

Source[b]	Composition
Hanford	Vitrified fission products in glass waste form; hot cell waste
INEEL	Activated metal
ORNL	Activated metal; isotope production waste; hot cell waste
WVDP	Activated metal; vitrified transuranic waste
Naval Reactors Facility at INEEL	Activated metal (zirconium alloy, Inconel, stainless steel)
Other generators	Stainless-steel sealed sources

a. Source: DIRS 104411-Picha (1998, all).
b. INEEL = Idaho National Engineering and Environmental Laboratory; ORNL = Oak Ridge National Laboratory; WVDP = West Valley Demonstration Project.

A.2.6.4 Final Waste Form

The final disposal method for DOE Special-Performance-Assessment-Required waste is not known. If the Department disposed of such waste in a repository, it is assumed that the material would be placed in a disposable package before shipment to the repository. The EIS assumes the use of a disposable canister similar to those used for naval fuels for all rail shipments and packages similar to a high-level radioactive waste canister for all truck shipments.

A.2.6.5 Waste Characteristics

The low-level waste from West Valley consists of material in the Head End Cells (5 cubic meters [177 cubic feet]) and remote-handled and contact-handled transuranic waste (545 cubic meters [19,000 cubic feet]). The estimated radioactivity of the material in the Head End Cells is 6,750 curies, while the activity of the remote-handled and contact-handled transuranic waste is not available at present (DIRS 104411-Picha 1998, all). The naval Special-Performance-Assessment-Required waste consists primarily of zirconium alloys, Inconel, and stainless steel (DIRS 124679-Beckett 1998, all); Table A-63 lists the specific radioactivity of the projected material 5 years after discharge.

The specific activity associated with the radium sources at Argonne National Laboratory-East has not been determined. However, in comparison to the other Special-Performance-Assessment-Required waste included in this section, its impact would be small.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

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101779	DOE 1998	DOE (U.S. Department of Energy) 1998. *Viability Assessment of a Repository at Yucca Mountain.* DOE/RW-0508. Overview and five volumes. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0027; MOL.19981007.0028; MOL.19981007.0029; MOL.19981007.0030; MOL.19981007.0031; MOL.19981007.0032.
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155100	DOE 1999	DOE (U.S. Department of Energy) 1999. *Idaho High-level Waste and Facilities Disposition Draft Environmental Impact Statement.* DOE/EIS-0287D. Idaho Falls, Idaho: U.S. Department of Energy, Idaho Operations Office. ACC: MOL.20001030.0151.
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104395	Heiser 1998	Heiser, M.B. 1998. "INEL HLW Vit Breakdown." Memorandum from M.B. Heiser to J. Rivers, March 5, 1998, EIS:AR-GEN-35642. ACC: MOL.19990511.0370.
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104406	Picha 1997	Picha, K.G., Jr. 1997. "Response to Repository Environmental Impact Statement Data Call for High-Level Waste." Memorandum from K.G. Picha, Jr. (DOE) to W. Dixon (YMSCO), September 5, 1997, with attachments. ACC: MOL.19970917.0273.
104407	Picha 1998	Picha, K.G., Jr. 1998. "Clarification of High-Level Waste and Special Performance Assessment Required Data for Repository Environmental Impact Statement." Memorandum from K.G. Picha, Jr. (DOE) to K. Skipper (YMSCO), May 8, 1998, EIS:AR-GEN-35723, with attachments. ACC: MOL.19990610.0297.

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101909	Plodinec, Moore, and Marra 1993	Plodinec, M.J.; Moore, F.S.; and Marra, S.L. 1993. *Reporting Dose and Heat Generation Rates of the DWPF Product (U).* WSRC-IM-91-116-12, Rev. 0. Aiken, South Carolina: Westinghouse Savannah River Company. TIC: 232736.
101913	Raddatz and Waters 1996	Raddatz, M.G. and Waters, M.D. 1996. *Information Handbook on Independent Spent Fuel Storage Installations.* NUREG-1571. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 231666.
104418	Rowland 1997	Rowland, T.J. 1997. "Repository Environmental Impact Statement Data Call for High-Level Waste." Memorandum from T.J. Rowland (DOE) to K.G. Picha (DOE), November 26, 1997, JLD:04-53159-435.5, with attachment. ACC: MOL.19990608.0048.
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104422	Stevenson 1997	Stevenson, B. 1997. "Delivery of Data Reports." Memorandum from B. Stevenson (DOE) to W. Dixon (DOE/YMSCO), October 21, 1997, with enclosures. ACC: MOL.19971119.0155.
104476	Taylor 1997	Taylor, W.J. 1997. "Response to Clarification Data for the Repository Environmental Impact Statement (EIS) Data Call Memorandum Dated October 3, 1997." Memorandum from W.J. Tayor (DOE) to K.G. Picha, Jr. (Office of Waste Management), November 17, 1997, EIS:AR-GEN-35721, with attachments. ACC: MOL.19990610.0295.
101941	USN 1996	USN (U.S. Department of the Navy) 1996. *Department of the Navy Final Environmental Impact Statement for a Container System for the Management of Naval Spent Nuclear Fuel.* DOE/EIS-0251. [Washington D.C.]: U.S. Department of Energy. TIC: 227671.

103500	WVNS n.d.	West Valley Nuclear Services Company n.d. *Waste Form Qualification Report (WQR), West Valley Demonstration Project.* WVDP-186, Rev. 1. West Valley, New York: West Valley Nuclear Services Company. TIC: 242094. In the Draft EIS, this reference was cited as WVNS 1996.
153072	Wheatley 2000	Wheatley, P.D. 2000. "Spent Nuclear Fuel Database." Letter from P.D. Wheatley (INEEL) to M.R. Arenaz (DOE), CCN 00-013570, September 22, 2000. ACC: MOL.200012140478.

transport of radionuclides from the engineered and natural barrier systems to the environment. Therefore, the long-term performance of the repository would be managed by appropriately spacing the waste packages within disposal drifts and the distances between disposal drifts, and by selectively placing spent nuclear fuel and high-level radioactive waste packages to account for their individual heat generation rates.

Alternatives

DOE has preliminarily identified for analysis in the EIS a full range of reasonable implementation alternatives for the construction, operation, and closure/post-closure of a repository at Yucca Mountain. These implementation alternatives are based on thermal load objectives and include High Thermal Load, Intermediate Thermal Load, and Low Thermal Load alternatives.

Under each implementation alternative, DOE will evaluate different spent nuclear fuel and high-level radioactive waste packaging and transportation options. DOE anticipates that these options would produce the broadest range of potential configurations for both surface facilities and possible operational and disposal conditions at the repository. Evaluation of these options will identify the full range of reasonably foreseeable impacts to human health and the environment associated with each implementation alternative.

High Thermal Load Alternative

Under the High Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would generate the upper range of repository temperatures while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the emplacement density would likely be greater than 80 MTHM per acre. This alternative would represent the highest repository thermal loading based on available information and expected test results.

Intermediate Thermal Load Alternative

Under the Intermediate Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would generate an intermediate range of repository temperatures (compared to the High and Low Thermal Load alternatives) while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the disposal density would likely range between 40 to 80 MTHM per acre.

Low Thermal Load Alternative

Under the Low Thermal Load implementation alternative, spent nuclear fuel and high-level radioactive waste would be disposed in an underground configuration that would provide the lowest potential repository thermal loading (based on available information and expected test results) while meeting performance objectives to isolate the material in compliance with Environmental Protection Agency standards and Nuclear Regulatory Commission requirements. Under this alternative, the disposal density would likely be less than 40 MTHM per acre.

Packaging Options

As part of each implementation alternative, two packaging options would be evaluated. Under Option 1, spent nuclear fuel assemblies would be packaged and sealed in multi-purpose canisters at the generator sites prior to being transported to the repository in Nuclear Regulatory Commission-certified casks. High-level radioactive waste also would be packaged and sealed in canisters prior to shipment in similar casks. Under Option 2, spent nuclear fuel assemblies (without canisters) and sealed canisters of high-level radioactive waste would be transported to the repository in Nuclear Regulatory Commission-certified casks. Under both options, assemblies and canisters with intact seals would be removed from the casks and placed in disposal containers at the repository.

DOE recognizes that it is likely that a mix of spent nuclear fuel assemblies and canisters (and canister systems) of spent nuclear fuel and vitrified high-level radioactive waste would arrive at the repository during disposal operations. However, since the specific mix is speculative, the above packaging options were chosen to produce the broadest range of potential configurations for both surface facilities and possible operational and disposal conditions at the repository. These options were also selected to reflect the potential range of exposures to workers and the public at the generator sites, along transportation routes, and at the repository from the packaging, transport, and disposal of spent nuclear fuel and high-level radioactive waste.

Transportation

As part of each implementation alternative, two national transportation options and three regional (i.e., within the State of Nevada) transportation options would be evaluated. These options would be expected to result in the broadest range of operating conditions relevant to potential impacts to human health and the environment.

In a national context, the first option would consist of shipping all spent nuclear fuel and high-level radioactive waste by truck, from the generator site to the repository.

The second national option would consist of shipment by rail, except from those generator sites (as many as 19) that may not have existing capabilities to load and ship rail casks. For such sites, the spent nuclear fuel would be transported by truck to the repository, or to a facility near the nuclear power plant where it would be transferred to rail cars for shipment to the repository.

In a regional context, there are three transportation options: two of these options apply to shipments that would arrive in Nevada by rail, and the third applies to shipments that would arrive in Nevada by legal weight truck.[7]

The first regional transportation option would consist of several rail corridors to the repository. The rail corridor option would involve identifying and applying siting criteria, based on engineering considerations (e.g., topography and soils), potential land use restrictions (e.g., wilderness areas and existing conflicting uses), and any other factors identified from the scoping process.

The second regional transportation option would involve the use of heavy haul truck[8] routes to the repository. The heavy haul option would include the construction and use of an intermodal transfer facility to receive shipments that would arrive in Nevada by rail; the intermodal transfer facility would be located at the beginning of the heavy haul route. The heavy haul option would include any need to improve the local transportation infrastructure.

The third regional transportation option would involve legal weight truck shipments directly to the repository. Under this option, a transfer facility would not be required.

No Action

The No Action alternative would evaluate termination of site

[7] A legal weight truck consists of a tractor, semi-trailer, and loaded cask, with a maximum gross weight of 80,000 pounds.

[8] A heavy haul truck consists of a tractor, semi-trailer, and loaded cask, with a gross weight in excess of 129,000 pounds.

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characterization activities at Yucca Mountain and the continued accumulation of spent nuclear fuel and high-level radioactive waste at commercial storage sites and DOE facilities. Spent nuclear fuel and high-level radioactive waste would continue to be managed for the foreseeable future at existing commercial storage sites and DOE facilities located in 34 States. The No Action alternative, although contrary to the Congressional desire to provide a permanent solution for isolation of the Nation's spent nuclear fuel and high-level radioactive waste, provides a baseline against which the implementation alternatives can be compared.

At the Yucca Mountain site, the surface facilities, excavation equipment, and other support facilities would be dismantled and removed for reuse or recycling, or would be disposed of in solid waste landfills. Disturbed surface areas would be reclaimed and excavated openings to the subsurface would be sealed and backfilled.

At commercial reactors, spent nuclear fuel would continue to be generated and stored in either water pools or in canisters, until storage space at individual reactors becomes inadequate, at which time reactor operations would cease. DOE-owned spent nuclear fuel and high-level radioactive waste would continue to be managed at three primary sitesÐthe Hanford Reservation, Savannah River Site, and the Idaho National Engineering Laboratory.

Environmental Issues To Be Examined in the EIS

This EIS will examine the site-specific environmental impacts from construction, operation, and eventual closure of a repository for spent nuclear fuel and high-level radioactive waste disposal at Yucca Mountain, Nevada. Transportation-related impacts of the alternatives will also be analyzed. Through internal discussion and outreach programs with the public, DOE is aware of many environmental issues related to the construction, operation, and closure/post-closure phases of such a repository. The issues identified here are intended to facilitate public scoping. The list is not intended to be all-inclusive or to predetermine the scope of the EIS, but should be used as a starting point from which the public can help DOE define the scope of the EIS.

- Radiological and non-radiological releases. The potential effects to the public and on-site workers from radiological and nonradiological releases;
- Public and Worker Safety and Health. Potential health and safety impacts (e.g., injuries) to on-site workers during the unloading, temporary surface storage, and underground emplacement of waste packages at Yucca Mountain;
- Transportation. The potential impacts associated with national and regional shipments of spent nuclear fuel and high-level radioactive waste from reactor sites and DOE facilities to the Yucca Mountain site will be assessed. Regional transportation issues include: (a) technical feasibility, (b) socioeconomic impacts, (c) land use and access impacts, and (d) impacts of constructing and operating a rail spur, a heavy haul route, and/or a transfer facility;
- Accidents. The potential impacts from reasonably foreseeable accidents, including any accidents with low probability but high potential consequences;
- Criticality. The likelihood that a self-sustaining nuclear chain reaction could occur and its potential consequences;
- Waste Isolation. Potential impacts associated with the long-term performance of the repository;
- Socioeconomic Conditions. Potential regional (i.e., in Nevada) socioeconomic impacts to the surrounding communities, including impacts on employment, tax base, and public services;
- Environmental Justice. Potential for disproportionately high and adverse impacts on minority or low-income populations;
- Pollution Prevention. Appropriate and innovative pollution prevention, waste minimization, and energy and water use reduction technologies to eliminate or significantly reduce use of energy, water, hazardous substances, and to minimize environmental impacts;
- Soil, Water, and Air Resources. Potential impacts to soil, water quality, and air quality;
- Biological Resources. Potential impacts to plants, animals, and habitat, including impacts to wetlands, and threatened and endangered species;
- Cultural Resources. Potential impacts to archaeological/historical sites, Native American resources, and other cultural resources;
- Cumulative impacts from the proposed action and implementing alternatives and other past, present, and reasonably foreseeable future actions;
- Potential irreversible and irretrievable commitment of resources.

Under the No Action alternative, potential environmental effects associated with the shutdown of site characterization activities at Yucca Mountain will be estimated. Potential environmental effects from the continued accumulation of spent nuclear fuel and high-level radioactive waste at commercial reactors and DOE sites will be addressed by summarizing previous relevant environmental analyses and by performing new analyses of representative sites, as appropriate. At the Yucca Mountain site, the potential environmental consequences from the reclamation of disturbed surface areas, and the sealing of excavated openings following the dismantlement and removal of facilities and equipment, will be quantified. These analyses would be similar in level of detail to the analyses of the implementing alternatives. At the commercial reactor and DOE sites, the potential environmental consequences will be addressed in terms of risk to the environment and the public from long-term management of spent nuclear fuel and high-level radioactive waste. In addition, the loss of storage capacity, the need for additional capacity, and their potential consequences to continued reactor operations, will be described.

Consultations With Other Agencies

The NWPA requires DOE to solicit comments on the EIS from the Department of the Interior, the Council on Environmental Quality, the Environmental Protection Agency, and the Nuclear Regulatory Commission (42 U.S.C. § 10134(a)(1)(D)). DOE also intends to consult with the Departments of the Navy and Air Force and will solicit comments from other agencies, the State of Nevada, affected units of local government, and Native American tribal organizations, regarding the environmental issues to be addressed by the EIS.

Relationship to Other DOE NEPA Reviews

DOE is preparing or has completed other NEPA documents that may be relevant to the Office of Civilian Radioactive Waste Management Program and this EIS. If appropriate, this EIS will incorporate by reference and update information taken from these other NEPA documents. These documents (described below) are available for inspection by the public at the DOE Freedom of Information Reading Room (1E–190), Forrestal Building, 1000 Independence Ave., S.W., Washington, D.C. and will be made available in Nevada at locations to be announced at the public scoping meetings. These documents include the following:

- *Environmental Assessment, Yucca Mountain Site*, Nevada Research and

Development Area, Nevada, DOE/RW–0073, 1986.

• *Environmental Assessment for a Monitored Retrievable Storage Facility,* DOE/RW–0035, 1986.

• *Environmental Impact Statement for a Multi-Purpose Canister System for the Management of Civilian and Naval Spent Nuclear Fuel.* The Notice of Intent was published on October 24, 1994 (59 FR 53442). The scoping process for this EIS has been completed and an Implementation Plan is being prepared. The Draft EIS is scheduled to be issued for public review in late 1995.

• *Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Environmental Impact Statement* [Final EIS issued April 1995 (DOE/EIS–0203–F); Record of Decision (60 FR 28680–96, June 1, 1995)]. This EIS analyzes the potential environmental consequences of managing DOE's inventory of spent nuclear fuel over the next 40 years. The Nevada Test Site was considered but was not selected as a DOE spent nuclear fuel management site.

• *Waste Management Programmatic Environmental Impact Statement* (formerly Environmental Management Programmatic EIS). A revised Notice of Intent was published January 24, 1995 (60 FR 4607). This Programmatic EIS will address impacts of potential DOE waste management actions for the treatment, storage, and disposal of waste. The Draft EIS is scheduled to be issued for public review in September 1995.

• *Environmental Impact Statement for a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* [Notice of Intent published October 21, 1993 (58 FR 54336)]. The draft EIS was issued for public review in March 1995 (DOE/EIS–0218D). This EIS addresses the potential environmental impacts of the proposed policy's implementation. Under the proposed policy, the United States could accept up to 22,700 foreign research reactor spent nuclear fuel elements over a 10–15 year period.

• *Environmental Impact Statement on the Transfer and Disposition of Surplus Highly Enriched Uranium* (formerly part of the Programmatic Environmental Impact Statement for Long-Term Storage and Disposition of Weapons-Usable Fissile Materials). The Notice of Intent was issued April 5, 1995 (60 FR 17344). This EIS will address disposition of DOE's surplus highly enriched uranium to support the President's Nonproliferation Policy. The Draft EIS is scheduled to be issued in September 1995.

• *Programmatic Environmental Impact Statement for Storage and Disposition of Weapons-Usable Fissile Materials* [Notice of Intent published June 21, 1994 (59 FR 31985)]. This Programmatic EIS will evaluate alternatives for long-term storage of all weapons-usable fissile materials (primarily plutonium and highly enriched uranium retained for strategic purposes—not surplus) and disposition of surplus weapons-usable fissile materials (excluding highly enriched uranium), so that risk of proliferation is minimized. The Nevada Test Site is a candidate storage site.

• *Tritium Supply and Recycling Programmatic Environmental Impact Statement.* A revised Notice of Intent was published October 28, 1994 (59 FR 54175), and the Draft Programmatic EIS was issued in March 1995 (60 FR 14433, March 17, 1995). Public hearings on the Draft Programmatic EIS were held in April 1995, and a Final Programmatic EIS is scheduled for October 1995. This EIS addresses how to best assure an adequate tritium supply and recycling capability. The Nevada Test Site is an alternative site for new tritium supply and recycling facilities.

• *Stockpile Stewardship and Management Programmatic Environmental Impact Statement.* A Notice of Intent was published June 14, 1995 (60 FR 31291). A prescoping workshop was held on May 19, 1995, and scoping meetings are scheduled to be held during July and August 1995. This Programmatic EIS will evaluate proposed future missions of the Stockpile Stewardship and Management Program and potential configuration (facility locations) of the nuclear weapons complex to accomplish the Stockpile Stewardship and Management Program missions. The Nevada Test Site is an alternative site for potential location of new or upgraded Stockpile Stewardship and Management Program facilities.

• *Site-Wide Environmental Impact Statement for the Nevada Test Site* [Notice of Intent published August 10, 1994 (59 FR 40897)]. This EIS will address resource management alternatives for the Nevada Test Site to support current and potential future missions involving defense programs, research and development, waste management, environmental restoration, infrastructure maintenance, transportation of wastes, and facility upgrades and alternative uses. The public scoping process has been completed, and the Implementation Plan was issued in July 1995. The Draft EIS is scheduled to be issued for public review in September 1995.

• *Environmental Impact Statement for the Continued Operation of the Pantex Plant and Associated Storage of Nuclear Weapon Components* [Notice of Intent published May 23, 1994 (59 FR 26635); an amended Notice of Intent published June 23, 1995 (60 FR 32661)]. This EIS will address the potential environmental impacts of the continued operation of the Pantex Plant, which includes near- to mid-term foreseeable activities and the nuclear component storage activities at other DOE sites associated with nuclear weapon disassembly operations at the Pantex Plant. The Nevada Test Site is being considered as an alternative site for relocation of interim plutonium pit storage.

Public Reading Rooms

Copies of the Implementation Plan, and the Draft and Final EISs, will be available for inspection during normal business hours at the following public reading rooms. DOE may establish additional information locations and will provide an updated list at the public scoping meetings.

Albuquerque Operations Office, National Atomic Museum, Bldg. 20358, Wyoming Blvd., S.E., Kirtland Air Force Base, Albuquerque, NM 87117. Attn: Diane Leute (505) 845–4378

Atlanta Support Office, U.S. Dept. of Energy, Public Reading Room, 730 Peachtree Street, Suite 876, Atlanta, GA 30308–1212. Attn: Nancy Mays/ Laura Nicholas (404) 347–2420

Bartlesville Project Office/National Institute for Petroleum and Energy Research, Library, U.S. Dept. of Energy, 220 Virginia Avenue, Bartlesville, OK 74003. Attn: Josh Stroman (918) 337–4371

Bonneville Power Administration, U.S. Dept. of Energy, BPA–C–KPS–1, 905 N.E. 11th Street, Portland, OR 97208. Attn: Sue Ludeman (503) 230–7334

Chicago Operations Office, Document Dept., University of Illinois at Chicago, 801 South Morgan Street, Chicago, IL 60607. Attn: Seth Nasatir (312) 996–2738

Dallas Support Office, U.S. Dept. of Energy, Public Reading Room, 1420 Mockingbird Lane, Suite 400, Dallas, TX 75247. Attn: Gailene Reinhold (214) 767–7040

Fernald Area Office, U.S. Dept. of Energy, Public Information Room, FERMCO, 7400 Willey Road, Cincinnati, OH 45239. Attn: Gary Stegner (513) 648–3153

Headquarters Office, U.S. Dept. of Energy, Room 1E–190, Forrestal Bldg.,

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1000 Independence Avenue, S.W., Washington, D.C. 20585. Attn: Gayla Sessoms (202) 586–5955

Idaho Operations Office, Idaho Public Reading Room, 1776 Science Center Dr., Idaho Falls, ID 83402. Attn: Brent Jacobson (208) 526–1144

Kansas City Support Office, U.S. Dept. of Energy, Public Reading Room, 911 Walnut Street, 14th Floor, Kansas City, MO 64106. Attn: Anne Scheer (816) 426–4777

Office of Civilian Radioactive Waste Management National Information Center, 600 Maryland Avenue, S.W., Suite 760, Washington, D.C. 20024. Attn: Paul D'Anjou (202) 488–6720

Oak Ridge Operations Office, U.S. Dept. of Energy, Public Reading Room, 55 South Jefferson Circle, Room 112, Oak Ridge, TN 37831–8510. Attn: Amy Rothrock (615) 576–1216

Oakland Operations Office, U.S. Dept. of Energy, Public Reading Room, EIC, 8th Floor, 1301 Clay Street, Room 700N, Oakland, CA 94612–5208. Attn: Laura Noble (510) 637–1762

Pittsburgh Energy Technology Center, U.S. Dept. of Energy, Bldg. 922/M210, Receiving Department, Building 166, Cochrans Mill Road, Pittsburgh, PA 15236–0940. Attn: Ann C. Dunlap (412) 892–6167

Richland Operations Office, U.S. Dept. of Energy, Public Reading Room, 100 Sprout Rd., Room 130 West, Mailstop H2–53, Richland, WA 99352. Attn: Terri Traub (509) 376–8583

Rocky Flats Field Office, Front Range Community College Library, 3645 West 112th Avenue, Westminster, CO 80030. Attn: Nancy Ben (303) 469–4435

Savannah River Operations Office, Gregg-Graniteville Library, University of S. Carolina-Aiken, 171 University Parkway, Aiken, SC 29801. Attn: James M. Gaver (803) 725–2889

Southeastern Power Administration, U.S. Dept. of Energy, Legal Library, Samuel Elbert Bldg., 2 South Public Square, Elberton, GA 30635–2496. Attn: Joel W. Seymour/Carol M. Franklin (706) 213–3800

Southwestern Power Administration, U.S. Dept. of Energy, Public Reading Room, 1 West 3rd, Suite 1600, Tulsa, OK 74103. Attn: Marti Ayers (918) 581–7426

Strategic Petroleum Reserve Project Management Office, U.S. Dept. of Energy, SPRPMO/SEB Reading Room, 900 Commerce Road East, New Orleans, LA 70123. Attn: Ulysess Washington (504) 734–4243

Yucca Mountain Science Centers

Yucca Mountain Science Center, U.S. 95—Star Route 374, Beatty, NV 89003. Attn: Marina Anderson (702) 553–2130

Yucca Mountain Science Center, 4101–B Meadows Lane, Las Vegas, NV 89107. Attn: Melinda D'ouville (702) 295–1312

Yucca Mountain Science Center, 1141 South Hwy. 160, Pahrump, NV 89041. Attn: Lee Krumm (702) 727–0896

TABLE 1.—SCOPING MEETINGS

Location of scoping meeting	Dates/times [1]
Pahrump Community Center, 400 N. Hwy. 160, Pahrump, NV 89048	Tuesday, August 29, 1995, morning/evening sessions.
Boise Centre on the Grove, 850 W. Front St., Boise, ID 83702	Wednesday, September 6, 1995, morning/evening sessions.
Lawlor Events Center, University of Nevada-Reno Campus, Reno, NV 89667.	Friday, September 8, 1995, morning/evening sessions.
University of Chicago, Downtown MBA Center, 450 N. Cityfront Plaza Drive, Chicago, IL 60611.	Tuesday, September 12, 1995, morning/evening sessions.
Cashman Field, 850 Las Vegas Blvd. North, Las Vegas, NV 89101	Friday, September 15, 1995, morning/evening sessions .
Denver Convention Complex, 700 14th Street, Denver, CO 80202	Tuesday, September 19, 1995, afternoon/evening sessions.
Sacramento Public Library, 828 I Street, Sacramento, CA 95814	Thursday, September 21, 1995, afternoon/evening sessions.
Arlington Community Center, 2800 South Center Street, Dallas, TX 76004.	Tuesday, September 26, 1995, afternoon/evening sessions.
Caliente Youth Center, Highway 93, Caliente, NV 89008	Thursday, September 28, 1995, morning/evening sessions.
Hilton Inn, 150 West 500 South, Salt Lake City, UT 84111	Thursday, October 5, 1995, afternoon/evening sessions.
Maritime Institute of Technology and Graduate Studies, 5700 Hammonds Ferry Rd., Linthicum (near Baltimore), MD 21090.	Wednesday, October 11, 1995, morning/evening sessions.
Russell Sage Conference Center, 45 Ferry St., Troy (Albany), NY 12180.	Friday, October 13, 1995, afternoon/evening sessions.
Georgia International Convention Center, 1902 Sullivan Road, College Park (Atlanta), GA 30337.	Tuesday, October 17, 1995, morning/evening sessions.
Penn Valley Community College, 3201 S.W. Trafficway, Kansas City, MO 64111.	Friday, October 20, 1995, afternoon/evening sessions.
Tonopah Convention Center, 301 Brougher, Tonopah, NV 89049	Tuesday, October 24, 1995, morning/evening sessions.

[1] Session times are as follows: Morning (8:30 a.m.–12:30 p.m.), Afternoon (12:00 a.m.–4:00 p.m.), Evening (6:00 p.m.–10:00 p.m.).

Issued in Washington, D.C., this 1st day of August, 1995.

Peter N. Brush,

Acting Assistant Secretary, Environment, Safety and Health.

[FR Doc. 95–19396 Filed 8–4–95; 8:45 am]

BILLING CODE 6450–01–P

31554 **Federal Register** / Vol. 64, No. 112 / Friday, June 11, 1999 / Notices

DEPARTMENT OF ENERGY

Floodplain and Wetlands Involvement; Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

AGENCY: Department of Energy.

ACTION: Notice of floodplain and wetlands involvement.

SUMMARY: The U.S. Department of Energy (DOE) is proposing to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain, Nye County, Nevada. As part of its proposal, DOE is considering shipping spent nuclear fuel and high-level radioactive waste in the State of Nevada over a rail line that would be constructed or over an existing highway route that may need upgrading to accommodate heavy-haul trucks. Portions of the rail corridor or highway route would cross perennial and ephemeral streams and their associated floodplains, as well as possible wetlands. Furthermore, portions of the transportation system in the immediate vicinity of the proposed repository would be located within the 100-year floodplains of Midway Valley Wash, Drillhole Wash, Busted Butte Wash and/or Fortymile Wash. No other aspect of repository-related operations or nuclear or nonnuclear repository facilities would be located within the 500-year or 100-year floodplains of these washes. In accordance with DOE regulations for Compliance with Floodplain/Wetlands Environmental Review Requirements (10 CFR Part 1022), DOE will prepare a floodplain and wetlands assessment commensurate with proposed decisions and available information. The assessment will be included in the Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. A draft of this EIS is scheduled to be published during the summer of 1999.

DATES: The public is invited to comment on this notice on or before July 1, 1999. Comments received after this date will be considered to the extent practicable.

ADDRESSES: Comments on this notice should be addressed to Ms. Wendy Dixon, EIS Project Manager, Yucca Mountain Site Characterization Office,

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U.S. Department of Energy, P.O. Box 30307, M/S 010, Las Vegas, Nevada 89036–0307. Comments also can be submitted via electronic mail to: eisr@notes.ymp.gov.

FOR FURTHER INFORMATION CONTACT:

Proposed Action: Ms. Wendy Dixon, EIS Project Manager, at the above address, or by calling (800)–881–7292.

Floodplain and Wetlands Environmental Review Requirements: Ms. Carol Borgstrom, Office of NEPA Policy and Assistance (EH–42), U.S. Department of Energy, 1000 Independence Avenue, S.W., Washington, D.C. 20585, (202)–586–4600 or leave a message at (800) 472–2756.

SUPPLEMENTARY INFORMATION: In accordance with the Nuclear Waste Policy Act, as amended, DOE is studying Yucca Mountain in Nye County, Nevada, to determine its suitability for the deep geologic disposal of commercial and DOE spent nuclear fuel and high-level radioactive waste. In 1989, DOE published a Notice of Floodplain/Wetlands Involvement (54 FR 6318, February 9, 1989) for site characterization at Yucca Mountain, and in 1992 published a Floodplain Statement of Findings (57 FR 48363, October 23, 1992).

DOE is now preparing an EIS (DOE–EIS–0250) to assess the potential environmental impacts from the construction, operation and monitoring, and eventual closure of the proposed geologic repository. DOE issued a Notice of Intent to prepare the EIS on August 7, 1995 (60 FR 40164). As part of its proposal, DOE is considering shipping spent nuclear fuel and high-level radioactive waste in the State of Nevada over a rail line that would be constructed or over an existing highway route that may need upgrading to accommodate heavy-haul trucks. For the rail mode, DOE is evaluating five potential corridors (Figure 1). For the heavy-haul truck mode, DOE is evaluating three potential locations for an intermodal transfer station associated with five potential highway routes (Figure 2; an intermodal transfer station is a facility at which shipping casks containing spent nuclear fuel and high-level radioactive waste would be transferred from trains to trucks, and empty shipping casks would be transferred from trucks to trains). The rail corridors would be about 400 meters (0.25 mile) wide. The Carlin Corridor would be the longest at 520 kilometers (323 miles) followed by the Caliente (513 kilometers, 319 miles), Caliente-Chalk Mountain (345 kilometers, 214 miles), Jean (181 kilometers, 112 miles), and Valley Modified (159 kilometers, 98 miles) corridors. The heavy-haul routes would utilize existing roads and rights-of-ways which typically would be less than 400 meters (0.25 miles) in width. The Caliente Route would be the longest at 533 kilometers (331 miles) followed by the Caliente-Las Vegas (377 kilometers, 234 miles), Caliente-Chalk Mountain (282 kilometers, 175 miles), Sloan/Jean (190 kilometers, 118 miles) and Apex/Dry Lake (183 kilometers, 114 miles) routes.

Portions of the transportation system in the immediate vicinity of the proposed repository are likely to be located within the 100-year floodplains of Midway Valley Wash, Drillhole Wash, Busted Butte Wash and/or Fortymile Wash (Figure 3). Fortymile Wash, a major wash that flows to the Amargosa River, drains the eastern side of Yucca Mountain. Midway Valley Wash, Drillhole Wash and Busted Butte Wash are tributaries to Fortymile Wash. Although water flow in Fortymile Wash and its tributaries is rare, the area is subject to flash flooding from thunderstorms and occasional sustained precipitation. There are no naturally occurring wetlands near the proposed repository facilities, although there are two man-made well ponds in Fortymile Wash that support riparian vegetation.

If the Proposed Action were implemented, DOE would use an existing road during construction of the repository that crosses the 100-year floodplain of Fortymile Wash (Figure 3). This road and other features of site characterization that involve floodplains have previously been examined by DOE and a Statement of Findings was issued in 1992 (57 FR 48363, October 23, 1992). It is uncertain at this time whether this existing road would require upgrading to accommodate the volume and type of construction vehicles.

In addition, transportation infrastructure would be constructed either in Midway Valley Wash, Drillhole Wash and Busted Butte Wash, or in Midway Valley Wash, Drillhole Wash and Fortymile Wash. The decision on which washes would be involved is dependent on future decisions regarding the mode of transport (rail or truck) which, in turn, would require the selection of one rail corridor or the selection of one site for an intermodal transfer station and its associated heavy-haul route. Structures that might be constructed in a floodplain could include one or more bridges to span the washes, one or more roads that could pass through the washes, or a combination of roads and culverts in the washes. No other aspect of repository-related operation of nuclear or nonnuclear facilities would be located within 500-year or 100-year floodplains.

Outside of the immediate vicinity of the proposed repository, the five rail corridors, and the three sites for an intermodal transfer station and associated five heavy-haul routes, would cross perennial and ephemeral streams, and possibly wetlands. It is likely that a combination of bridges, roads and culverts, or other engineered features, would be needed to span or otherwise cross the washes and possible wetlands, although the location of such structures is uncertain at this time.

DOE will prepare an initial floodplain and wetlands assessment commensurate with the proposed decisions and available information. This assessment will be included in the Draft EIS that is scheduled to be issued for public comment later this summer. If, after a possible recommendation by the Secretary of Energy, the President considers the site qualified for an application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. If the site designation becomes effective, the Secretary of Energy will submit to the Nuclear Regulatory Commission a License Application for a construction authorization. DOE would then probably select a rail corridor or a site for an intermodal transfer station among those considered in the EIS. Following such a decision, additional field surveys, environmental and engineering analyses, and National Environmental Policy Act reviews would likely be needed regarding a specific rail alignment for the selected corridor or the site for the intermodal transfer station and its associated heavy-haul truck route. When more specific information becomes available about activities proposed to take place within floodplains and wetlands, DOE will conduct further environmental review in accordance with 10 CFR Part 1022. Information that would be considered in a subsequent assessment includes, for example, the identification of 500-year and 100-year floodplains among feasible alignments of the selected rail corridor or the site of the intermodal transfer station and its associated heavy-haul route, identification of individual wetlands, and whether the floodplains and wetlands could be avoided. If the floodplains and wetlands could not be avoided, information on specific engineering designs and associated construction activities in the floodplains and wetlands also would be needed to permit a more detailed assessment and

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to ensure that DOE minimizes potential harm to or within any affected floodplains or wetlands.

Issued in Las Vegas, Nevada, on the 4th day of June 1999.

Wendy Dixon,

EIS Project Manager.

BILLING CODE 6450–01–P

48996 Federal Register / Vol. 64, No. 174 / Thursday, September 9, 1999 / Notices

DEPARTMENT OF ENERGY

Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

AGENCY: Office of Civilian Radioactive Waste Management, Department of Energy.

ACTION: Notice of Public Hearings.

SUMMARY: On August 13, 1999, the U.S. Department of Energy (DOE) published a Notice of Availability (64 FR 44200) of its Draft Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DOE/EIS–0250–D) and announced a 180-day public comment period ending February 9, 2000. The Draft EIS provides information on potential environmental impacts that could result from a proposed action to construct, operate and monitor, and eventually close a repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain in Nye County, Nevada.

The public is invited to submit written and oral comments at the 16 public hearings listed at the end of this notice.

DATES: DOE will consider all comments transmitted or postmarked by February 9, 2000. Comments submitted after this date will be considered to the extent practicable.

ADDRESSES: Written comments should be directed to: Ms. Wendy R. Dixon, EIS Project Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307.

Written comments may be transmitted by facsimile to 1–800–967–0739 and should include the following identifier: "Yucca Mountain Draft EIS."

Written comments may be submitted over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

FOR FURTHER INFORMATION CONTACT: Ms. Wendy R. Dixon, EIS Project Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

SUPPLEMENTARY INFORMATION: Copies of the Draft EIS have been provided to federal, state, tribal, and local government agencies and interested parties. In addition, the Draft EIS is available on the internet via the DOE National Environmental Policy Act (NEPA) website at *http://www.tis.eh.doe.gov/nepa* under the listing DOE NEPA Analyses, the Yucca Mountain Project website at *http://www.ymp.gov* under the listing Environmental Impact Statement, and at 38 public reading rooms across the country. Copies of the Draft EIS may be requested by calling 1–800–967–3477.

A complete set of all hard copy references used in the preparation of the Draft EIS are available for review at four public reading rooms: University of Nevada—Las Vegas, Nevada; University of Nevada—Reno, Nevada; Yucca Mountain Science Center—Pahrump, Nevada; and the DOE Headquarters Office in Washington, DC. Noncopyrighted references are available in the Yucca Mountain Science Center in Beatty, Nevada, as well as on CD-ROMs in an additional 33 public reading rooms across the nation. Noncopyrighted references are also available on the Yucca Mountain Project website at *http://www.ymp.gov*.

The public is invited to submit written and oral comments at the 16 public hearings listed at the end of this notice. The first hour of each hearing will include a brief overview presentation on the Draft EIS and a question and answer session. The remainder of the hearing will be an opportunity to provide comments for the record. To schedule a time to provide oral comments during the hearings, please call 1–800–967-3477. Persons wishing to provide oral comments who have not registered in advance may register at each hearing.

Public hearings will be held on the following dates at the following locations:

1. September 27, 1999, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, Amargosa Valley Community Center, 821 East Farm Road, Amargosa Valley, Nevada 89020.
2. September 30, 1999, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, Bob Ruud Community Center, 150 North Highway 160, Pahrump, Nevada 89048.
3. October 4, 1999, 10:00 am–1:00 pm, 6:00 pm–10:00 pm, Goldfield Community Center, 403 Crook Street, Goldfield, Nevada 89013.
4. October 5, 1999, 10:00 am–1:00 pm, 6:00 pm–10:00 pm, Boise Centre on the Grove, 850 West Front Street, Boise, Idaho 83702.
5. October 19, 1999, 10:00 am–1:00 pm, 4:00 pm–8:00 pm, Bristlecone Convention Center, 150 Sixth Street, Ely, Nevada 89301.
6. October 21, 1999, 12:00 pm–3:00 pm, 6:00 pm–10:00 pm, Georgia International Convention Center, 1902 Sullivan Road, College Park, Georgia 30337.
7. October 26, 1999, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, Hall of States, 444 North Capitol Street, N.W., Washington, DC 20001.
8. November 4, 1999, 12:00 pm–3:00 pm, 7:00 pm–10:00 pm, Statham Hall, 138 North Jackson Street, Lone Pine, California 93545.
9. November 9, 1999, 12:00 pm–3:00 pm, 6:00 pm–10:00 pm, Caliente Youth Center, U.S. Highway 93 North, Caliente, Nevada 89008.
10. November 16, 1999, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, Denver

Convention Complex, 700 14th Street, Denver, Colorado 80202.

11. December 1, 1999, 12:00 pm–3:00 pm, 6:00 pm–10:00 pm, Lawlor Events Center, 1664 North Virginia Street, Reno, Nevada 89557.

12. December 7, 1999, 11:00 am–2:00 pm, 5:30 pm–9:30 pm, Austin Town Hall, 137 Court Street, Austin, Nevada 89310.

13. December 9, 1999, 10:00 am–1:00 pm, 6:00 pm–10:00 pm, Crescent Valley Town Hall, 5045 Tenabo Avenue, Crescent Valley, Nevada 89821.

14. January 11, 2000, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, Grant Sawyer State Building, 555 East Washington, Las Vegas, Nevada 89101.

15. January 13, 2000, 10:00 am–1:00 pm, 6:00 pm–10:00 pm, Salt Lake City Hilton Inn, 150 West 500 South, Salt Lake City, Utah 84101.

16. January 20, 2000, 11:00 am–2:00 pm, 6:00 pm–10:00 pm, America's Center, 701 Convention Plaza, St. Louis, Missouri 63101.

Issued in Washington, DC, Sept. 2, 1999.

Ronald A. Milner,

Acting Deputy Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 99–23420 Filed 9–8–99; 8:45 am]

BILLING CODE 6450–01–P

55260 Federal Register / Vol. 64, No. 196 / Tuesday, October 12, 1999 / Notices

DEPARTMENT OF ENERGY

Additional Public Hearing for Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Office of Civilian Radioactive Waste Management (OCRWM), Department of Energy (DOE).

ACTION: Notice of additional public hearing.

SUMMARY: On August 13, 1999, the U.S. Department of Energy (DOE) published a Notice of Availability (64 FR 44200) of its Draft Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DOE/EIS–0250–D) and announced a 180-day public comment period ending February 9, 2000. Subsequently, 16 public hearings were announced on September 9, 1999 (64 FR 48996). DOE is now announcing one additional public hearing. To schedule a time to provide oral comments during the hearings, please call 1–800–967–3477. Persons wishing to provide oral comments who have not registered in advance may register at the hearings.

DATES: The additional public hearing will be held on December 2, 1999, from 12:00 noon to 3:00 p.m. and from 6:00 p.m. to 10:00 p.m., in Carson City, Nevada.

ADDRESSES: The additional public hearing will be held at the following location: Carson City, Nevada—Nevada State Legislature, Room 4100, 401 South Carson Street, Carson City, Nevada 89701.

FOR FURTHER INFORMATION CONTACT: Ms. Wendy R. Dixon, EIS Project Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

SUPPLEMENTARY INFORMATION: Public hearings have been scheduled for the following dates at the following locations:

1. September 27, 1999, 11:00 am—2:00 pm, 6:00 pm—10:00 pm, Amargosa Valley Community Center, 821 East Farm Road, Amargosa Valley, Nevada 89020
2. September 30, 1999, 11:00 am—2:00 pm, 6:00 pm—10:00 pm, Bob Ruud Community Center, 150 North Highway 160, Pahrump, Nevada 89048
3. October 4, 1999, 10:00 am—1:00 pm, 6:00 pm—10:00 pm, Goldfield Community Center, 403 Crook Street, Goldfield, Nevada 89013
4. October 5, 1999, 10:00 am—1:00 pm, 6:00 pm—10:00 pm, Boise Centre on the Grove, 850 West Front Street, Boise, Idaho 83702
5. October 19, 1999, 10:00 am—1:00 pm, 4:00 pm—8:00 pm, Bristlecone Convention Center, 150 Sixth Street, Ely, Nevada 89301
6. October 21, 1999, 12:00 pm—3:00 pm, 6:00 pm—10:00 pm, Georgia International Convention Center, 1902 Sullivan Road, College Park, Georgia 30337
7. October 26, 1999, 11:00 am—2:00 pm, 6:00 pm—10:00 pm, Hall of States, 444 North Capitol Street, N.W., Washington, DC 20001
8. November 4, 1999, 12:00 pm—3:00 pm, 7:00 pm—10:00 pm, Statham Hall, 138 North Jackson Street, Lone Pine, California 93545
9. November 9, 1999, 12:00 pm—3:00 pm, 6:00 pm—10:00 pm, Caliente Youth Center, U.S. Highway 93 North, Caliente, Nevada 89008
10. November 16, 1999, 11:00 am—2:00 pm, 6:00 pm—10:00 pm, Denver Convention Complex, 700 14th Street, Denver, Colorado 80202
11. December 1, 1999, 12:00 pm—3:00 pm, 6:00 pm—10:00 pm, Lawlor Events Center, 1664 North Virginia Street, Reno, Nevada 89557
12. December 2, 1999, 12:00 pm—3:00 pm, 6:00 pm—10:00 pm, Nevada State Legislature, Room 4100, 401 South Carson Street, Carson City, Nevada 89701
13. December 7, 1999, 11:00 am—2:00 pm, 5:30 pm—9:30 pm, Austin Town Hall, 137 Court Street, Austin, Nevada 89310
14. December 9, 1999, 10:00 am—1:00 pm, 6:00 pm—10:00 pm, Crescent Valley Town Hall, 5045 Tenabo Avenue, Crescent Valley, Nevada 89821
15. January 11, 2000, 11:00 amÐ2:00 pm, 6:00 pm—10:00 pm, Grant Sawyer State Building, 555 East Washington, Las Vegas, Nevada 89101
16. January 13, 2000, 10:00 am—1:00 pm, 6:00 pm—10:00 pm, Salt Lake City Hilton Inn, 150 West 500 South, Salt Lake City, Utah 84101
17. January 20, 2000, 11:00 am—2:00 pm, 6:00 pm—10:00 pm, America's Center, 701 Convention Plaza, St. Louis, Missouri 63101

Issued in Washington, DC, October 4, 1999.

Lake Barrett,

Acting Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 99–26552 Filed 10–8–99; 8:45 am]

BILLING CODE 6450–01–P

442 Federal Register / Vol. 65, No. 3 / Wednesday, January 5, 2000 / Notices

DEPARTMENT OF ENERGY

Additional Public Hearings for Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Office of Civilian Radioactive Waste Management, Department of Energy.

ACTION: Notice of additional public hearings.

SUMMARY: On August 13, 1999, the U.S. Department of Energy (DOE) published a Notice of Availability (64 FR 44200) of its *Draft Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (DOE/EIS–0250–D) and announced a 180-day public comment period ending February 9, 2000. Subsequently, 16 public hearings were announced on September 9, 1999 (64 FR 48996), and one additional hearing was announced on October 12, 1999 (64 FR 55260). DOE is now announcing three additional public hearing locations: Lincoln, NE; Cleveland, OH; and Chicago, IL. To schedule a time to provide oral comments during these hearings, please call 1–800–967–3477. Persons wishing to provide oral comments who have not registered in advance may register at the hearings.

DATES: The three additional public hearings will be held from 11:00 a.m. until 2:00 p.m. and from 6:00 p.m. until 9:00 p.m. on the following dates at the following locations: January 24, 2000, in Lincoln, NE; January 28, 2000, in Cleveland, OH; and February 1, 2000, in Chicago, IL.

ADDRESSES: The three additional public hearings will be held at the following locations:

Lincoln, NE, Ramada Inn—Airport, 1101 West Bond Street, Lincoln, Nebraska 68521

Cleveland, OH, Holiday Inn Lakeside City Center, 1111 Lakeside Avenue, Cleveland, Ohio 44114

Chicago, IL, Hotel Intercontinental, 505 North Michigan Avenue, Chicago, Illinois 60611

FOR FURTHERINFORMATION CONTACT: Ms. Wendy R. Dixon, EIS Program Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739. Copies of the document may also be requested by telephone (1–800–967–3477) or over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

Issued in Washington, DC, December 29, 1999.

Ivan Itkin,

Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 00–192 Filed 1–4–00; 8:45 am]

BILLING CODE 6717–01–P

44200 Federal Register / Vol. 64, No. 156 / Friday, August 13, 1999 / Notices

DEPARTMENT OF ENERGY

Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Office of Civilian Radioactive Waste Management, Department of Energy.

ACTION: Notice of availability.

SUMMARY: The Department of Energy (DOE) announces the availability of the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DOE/EIS–0250D). The Department has prepared this Draft EIS in accordance with the Nuclear Waste Policy Act of 1982, as amended (NWPA), the National Environmental Policy Act of 1969 (NEPA), the Council on Environmental Quality (CEQ) regulations that implement the procedural provisions of NEPA (40 CFR Parts 1500–1508), and the DOE procedures implementing NEPA (10 CFR Part 1021). The Draft EIS provides information on potential environmental impacts that could result from a Proposed Action to construct, operate and monitor, and eventually close a repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain in Nevada. The Draft EIS also considers the potential environmental impacts from an alternative referred to as the No-Action Alternative, under which a repository would not be developed at Yucca Mountain. The locations of the public hearings to receive comments on the Draft EIS are listed below.

DATES: Comments on the Draft EIS will be accepted during a 180-day public comment period, which ends on February 9, 2000. DOE will consider comments received after February 9, 2000, to the extent practicable. DOE will conduct public hearings on the Draft EIS and will announce the dates in the **Federal Register** in the near future.

ADDRESSES: Written comments, requests for further information on the Draft EIS or the public hearings, and requests for copies of the document (or a CD–ROM version) should be directed to: Ms. Wendy R. Dixon, EIS Project Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

Written comments transmitted by facsimile should include the following identifier: "Yucca Mountain Draft EIS." Addresses of the locations where the Draft EIS will be available for public review are listed in this Notice under "Availability of the Draft EIS."

Written comments or requests for copies of the document may also be submitted over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

FOR FURTHER INFORMATION CONTACT: Ms. Wendy R. Dixon, EIS Project Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

General information on the DOE NEPA process may be requested from: Ms. Carol M. Borgstrom, Director, Office of NEPA Policy and Assistance (EH–42), U.S. Department of Energy, 1000 Independence Ave., SW, Washington, DC 20585, Telephone 1–202–586–4600, or leave a message at 1–800–472–2756.

SUPPLEMENTARY INFORMATION:

Background

On August 7, 1995, the Department published a Notice of Intent (60 FR 40164) to prepare an Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada. The purpose of the Notice of Intent was to inform the public of the proposed scope of the Repository EIS, to solicit public input, and to announce that scoping meetings would be held from August through October 1995. During that period, 15 public scoping meetings were held throughout the United States to obtain public comments regarding the scope, alternatives, and issues that should be addressed in the EIS. The scoping period closed on December 5, 1995. Due to subsequent budget reductions, EIS activities were deferred until Fiscal Year 1997. In May 1997, DOE published Summary of Public Scoping Comments Related to the Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-level Radioactive Waste at Yucca Mountain, Nye County, Nevada, which summarized the comments received by DOE during the scoping process and described how DOE planned at that time to address issues raised during scoping. A Notice of Availability for the Summary of Public Scoping Comments document was published on July 9, 1997 (62 FR 36789).

Alternatives Considered

The Draft EIS evaluates a Proposed Action and a No-Action Alternative. Under the Proposed Action, DOE would construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain for the disposal of as much as 70,000 metric tons of heavy metal (MTHM) of spent nuclear fuel and high-level radioactive waste. The Proposed Action includes the transportation of spent nuclear fuel and high-level radioactive waste to Yucca Mountain from commercial and DOE sites. Under the No-Action Alternative, DOE would end site characterization activities at Yucca Mountain, and commercial and DOE sites would

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continue to store spent nuclear fuel and high-level radioactive waste, packaged as necessary for their safe on-site management.

DOE developed implementing alternatives and analytical scenarios for estimating in the Draft EIS the reasonably foreseeable environmental impacts that could result from the Proposed Action. For example, DOE evaluated three thermal load scenarios, which correspond to a relatively high emplacement density of spent nuclear fuel and high-level radioactive waste (high thermal load—85 MTHM per acre), a relatively low emplacement density (low thermal load—25 MTHM per acre), and an intermediate case—60 MTHM per acre. DOE recognizes, however, that if the site is eventually approved for development of a repository, the designs of repository surface and subsurface facilities, and plans for the construction, operation and monitoring, and closure of the repository would continue to evolve and would depend on the outcome of the Nuclear Regulatory Commission's licensing review of the repository.

Two national transportation scenarios are evaluated in the Draft EIS. The mostly legal-weight truck [1] scenario assumes that most spent nuclear fuel and high-level radioactive waste would be shipped to the repository by legal-weight truck over existing highways, with a few exceptions. The mostly rail scenario assumes that most spent nuclear fuel and high-level radioactive waste would be shipped to Nevada by rail, with a few exceptions (based largely on the on-site loading limitations at some commercial sites). The Nevada transportation implementing alternatives parallel the national transportation scenarios; however, because no rail access currently exists to the repository site, the EIS considers different implementing alternatives for the construction of either a new branch rail line to the proposed repository, or an intermodal transfer station [2] with associated highway improvements for heavy-haul trucks.[3]

The No-Action Alternative considers two scenarios. Scenario 1 assumes that spent nuclear fuel and high-level radioactive waste would remain at the 72 commercial and 5 DOE sites under effective institutional control for at least 10,000 years. Scenario 2 also assumes spent nuclear fuel and high-level radioactive waste would remain at the 77 sites, but under effective institutional control for only about 100 years.

[1] Truck with a gross vehicle weight (both truck and cargo) of less than 80,000 pounds.

[2] An intermodal transfer station is a facility at the juncture of rail and road transportation used to transfer shipping casks containing spent nuclear fuel and high-level radioactive waste from rail to truck and empty casks from truck to rail.

[3] Shipment of a rail cask (weighing up to 300,000 pounds) on a special truck and trailer combination that would have a total weight of approximately 500,000 pounds.

Public Hearings and Invitation To Comment

The public is invited to provide oral and written comments on the Repository Draft EIS during the public comment period that ends on February 9, 2000. DOE will consider comments received during the comment period in preparation of the Final EIS. Comments received after February 9, 2000, will be considered to the extent practicable.

The Department will hold 16 public hearings (each following the same format in either the mid-morning or afternoon and evening) to receive oral and written comments from members of the public. The public hearings are currently planned to be held in the following Nevada locations: Pahrump, Goldfield, Caliente, Las Vegas, Reno, Austin, Crescent Valley, Amargosa Valley and Ely. Other hearing locations will include Washington, DC; Atlanta, Georgia; Denver, Colorado; Boise, Idaho; Salt Lake City, Utah; St. Louis, Missouri; and Lone Pine, California. DOE will publish the dates, times, and specific locations in the **Federal Register**, and will notify all recipients of the Draft EIS and the media in writing as soon as this information is available. In addition, this information will be available on the Yucca Mountain website at *http://www.ymp.gov* and on the toll-free information line at 1–800–967–3477.

Each of the public hearings will include a brief session in which an overview of the Draft EIS will be presented, a general question-and-answer session, and an opportunity to provide comments for the record. Members of the public who plan to present oral comments are asked to register in advance by calling 1–800–967–3477.

Availability of the Draft EIS

Copies of the Draft EIS are being distributed to Federal, State, Indian tribal, and local officials, agencies, and organizations and individuals who have indicated an interest in the EIS process. Copies of the document may also be requested by telephone (1–800-967–3477) or over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov,* under the listing "Environmental Impact Statement."

Copies of references considered in preparation of the Draft EIS are available at the following Public Reading Rooms: University of Nevada—Las Vegas, Nevada; University of Nevada—Reno, Nevada; Beatty Yucca Mountain Science Center, Nevada; and the DOE Headquarters Office in Washington, DC. Addresses of these Public Reading Rooms and of other Public Reading Rooms and libraries where the Draft EIS is available for public review are listed below.

Public Reading Rooms

Inyo County—Contact: Andrew Remus; (760) 878–0447; Inyo County Yucca Mountain Repository Assessment Office; 168 North Edwards Street; Post Office Drawer L; Independence, CA 93526

Oakland Operations Office—Contact: Annette Ross; (510) 637–1762; U. S. Department of Energy Public Reading Room; EIC; 1301 Clay Street, Room 700N; Oakland, CA 94612–5208

National Renewable Energy Laboratory—Contact: Sarah Manion; (303) 275–4709; Public Reading Room; 1617 Cole Boulevard; Golden, CO 80401

Rocky Flats Public Reading Room—Contact: Ann Smith; (303) 469–4435; College Hill Library; 3705 112th Avenue B121; Westminster, CO 80030

Headquarters Office—Contact: Carolyn Lawson; (202) 586–3142; U.S. Department of Energy; Room 1E–190, Forrestal Building; 1000 Independence Avenue, SW; Washington, DC 20585

Atlanta Support Office—Contact: Nancy Mays/Laura Nicholas; (404) 347–2420; Department of Energy; Public Reading Room; 730 Peachtree Street, Suite 876; Atlanta, GA 30308–1212

Southeastern Power Administration—Contact: Joel W. Seymour/Carol M. Franklin; (706) 213–3800/(706) 213–3813; U.S. Department of Energy; Reading Room; Samuel Elbert Building; 2 South Public Square; Elberton, GA 30635–2496

Boise State University Library—Contact: Adrien Taylor; (208) 385–1621; Government Documents; 1910 University Drive; P.O. Box 46; Boise, ID 83707–0046

Idaho Operations Office—Contact: Brent Jacobson/Gail Willmore; (208) 526–1144; Public Reading Room; 1776 Science Center Drive; Idaho Falls, ID 83402

Chicago Operations Office—Contact: John Shuler; (312) 996–2738; Document Department; University of Illinois at Chicago; 801 South Morgan Street; Chicago, IL 60607

Strategic Petroleum Reserve Project Management Office—Contact: Deanna Harvey; (504) 734–4316; U.S. Department of Energy; SPRPMO/SEB

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Reading Room; 850 Commerce Road, East; New Orleans, LA 70123
Lander County—Contact: Tammy Manzini; (775) 964–2447; 610 Main Street; (P.O. Box 10); Austin, NV 89310
Beatty Yucca Mountain Science Center—Contact: Marina Anderson; (775) 553–2130; 100 North E Avenue; Beatty, NV 89003
Lincoln County—Contact: Eve Culverwell; (775) 726–3511; Box 1068 100 Depot Avenue; Caliente, NV 89008
Nevada State Clearinghouse—Contact: Heather Elliot; (775) 684–0209; Department of Administration; 209 Musser Street, Room 200; Carson City, NV 89701
White Pine County—Contact: Debra Kolkman; (775) 289–2033; 959 Campton Street; Ely, NV 89301
Eureka County—Contact: Leonard Fiorenzi; (775) 237–5372; Courthouse Annex; (P.O. Box 714); Eureka, NV 89316
Churchill County—Contact: Alan Kalt; (775) 423–5136; 190 West First Street; Fallon, NV 89046–2478
Esmeralda County—Contact: Tony Cain; (775) 485–3419; Repository Oversight Program; Elliot Street between Franklin and Euclid; P.O. Box 490; Goldfield, NV 89013
Mineral County—Contact: Commissioner Jackie Wells; (775) 945–2484; First & A Streets; (P.O. Box 1600); Hawthorne, NV 89415
Clark County—Contact: Dennis Bechtel; (702) 455–5175; 500 South Grand Central Parkway #3012; (P.O. Box 551751); Las Vegas, NV 89155–1751
Las Vegas, Nevada—Contact: Reference Desk; (702) 895–3409; University of Nevada Las Vegas; James R. Dickinson Library; Government Publications; 4505 Maryland Parkway; Las Vegas, NV 89154–7013
Las Vegas Yucca Mountain Science Center—Contact: Terri Brown; (702) 295–1312; 4101–B Meadows Lane; Las Vegas, NV 89107
Nye County—Contact: Les Bradshaw; (775) 727–7727; c/o Department of Natural Resources and Federal Facilities; 1210 E. Basin Avenue; Pahrump, NV 89048
Pahrump Yucca Mountain Science Center—Contact: Gordon Froman; (775) 727–0896; 1141 South Highway 160; Pahrump NV, 89041
Reno, Nevada—Contact: Kathie Brinkerhoff; (775) 784–6500, x-258; University of Nevada, Reno; The University of Nevada Libraries; Business and Government Information Center M/S 322; 1664 N. Virginia Street; Reno, NV 89557–0044
Albuquerque Operations Office—Contact: Shawna Schwartz; (702) 845–4939; U.S. DOE Contract Reading Room; Kirtland Air Force Base; Pennsylvania and H Street; Building 388; Albuquerque, NM 87116
Fernald Area Office—Contact: Gary Stegner; (513) 648–7480; U.S. Department of Energy; Public Information Room; 7400 Willey Road; Cincinnati, OH 45239
Bartlesville Project Office/National Institute for Petroleum and Energy ResearchÐContact: Josh Stroman; (918) 337–4371; BPO/NIPER Library; U.S. Department of Energy; 220 Virginia Avenue; Bartlesville, OK 74003
Southwestern Power Administration—Contact: Pam Bland; (918) 595–6624; U.S. Department of Energy; Public Reading Room; 1 West 3rd, Suite 1600; Tulsa, OK 74101
Bonneville Power Administration—Contact: Jean Pennington; (503) 230–7334; U.S. Department of Energy; BPA–C–ACS–1; 905 NE 11th Street; Portland, OR 97208
Pittsburgh Energy Technology Center—Contact: Ann C. Dunlap; (412) 892–6167; U.S. Department of Energy; Building 922/M210; Cochrans Mill Road; Pittsburgh, PA 15236–0940
Savannah River Operations Office—Contact: David Darugh; (803) 725–2497; Gregg-Graniteville Library; University of South Carolina—Aiken; 171 University Parkway; Aiken, SC 29801
University of South Carolina—Contact: Lester Duncan; (803) 777–4841; Thomas Cooper Library; Documents/Microforms Department; Green and Sumter Streets; Columbia, SC 29208
Oak Ridge Operations Office—Contact: Amy Rothrock/Teresa Brown; (423) 576-1216/(423) 241–4780; U.S. Department of Energy; Public Reading Room; P.O. Box 2001; American Museum of Science and Energy; 300 S. Tulane Avenue; Oak Ridge, TN 37831
Southern Methodist University—Contact: Stephen Short; (214) 768–2561; Central Union Libraries Fondren Library; Government Information; Airline and McFarland Streets; Dallas, TX 75275–0135
University of Utah—Contact: Walter Jones; (801) 581–8863; Marriott Library Special Collections; 295 South 15th East; Salt Lake City, UT 84112–0860
Richland Operations Center—Contact: Terri Traub; (509) 372–7443; U.S. Department of Energy; Public Reading Room; 2770 University Drive; Room 101L; PO Box 999; Mailstop H2–53; Richland, WA 99352

Issued in Washington, DC, August 5, 1999.

Lake Barrett,

Acting Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 99–20661 Filed 8–12–99; 8:45 am]

BILLING CODE 6450–01–P

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DEPARTMENT OF ENERGY

Comment Period Extension and Additional Public Hearing for Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Office of Civilian Radioactive Waste Management, Department of Energy.

ACTION: Notice of comment period extension and additional public hearing.

SUMMARY: On August 13, 1999, the U.S. Department of Energy (DOE) published a Notice of Availability (64 FR 44200) of its Draft Environmental Impact Statement (EIS) for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (DOE/EIS–0250–D) and announced a 180-day public comment period ending February 9, 2000. Based on input from the public, DOE is now announcing an additional public hearing in San Bernardino, California. The comment period is being extended to February 28, 2000.

DATES: The additional public hearing will be held on February 22, 2000, from 11:00 a.m. until 2:00 p.m. and from 6:00 p.m. until 9:00 p.m. The comment period for the Draft EIS is extended to February 28, 2000.

ADDRESSES: The additional public hearing will be held at the following location: Radisson Hotel, 295 North E. Street, San Bernardino, CA 92401.

Written comments on the Draft EIS should be directed to: Ms. Wendy R. Dixon, EIS Program Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307. Comments may also be transmitted by facsimile to 1–800–967–0739 and should include the following identifier: "Yucca Mountain Draft EIS." Comments may be submitted over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

INVITATION TO COMMENT: The public is invited to provide comments on the Draft EIS during the comment period that ends on February 28, 2000. DOE will consider comments received during the comment period in preparation of the Final EIS. Comments received after February 28, 2000 will be considered to the extent practicable.

FOR FURTHER INFORMATION CONTACT: Ms. Wendy R. Dixon, EIS Program Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, NV 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739. Copies of the document may also be requested by telephone (1–800–967–3477) or over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement"; the Draft EIS also may be viewed on this website.

Issued in Washington, DC, February 2, 2000.

Ivan Itkin,

Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 00–2714 Filed 2–7–00; 8:45 am]

BILLING CODE 6450–01–P

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DEPARTMENT OF ENERGY

Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada

AGENCY: Department of Energy (DOE).

ACTION: Notice of availability and opportunity for comment.

SUMMARY: The Department of Energy (DOE) announces the availability of a Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Draft EIS) (DOE/EIS–0250D–S). The Department has prepared this Supplement in accordance with the Nuclear Waste Policy Act of 1982, as amended (NWPA), the National Environmental Policy Act of 1969, as amended (NEPA), the Council on Environmental Quality regulations that implement the procedural provisions of NEPA, and the DOE procedures implementing NEPA. The Council on Environmental Quality NEPA regulations state that an agency may prepare a supplement when it determines that the purposes of NEPA will be furthered by doing so. As anticipated, design enhancements of the proposed repository at Yucca Mountain have evolved since DOE issued the Draft EIS in August 1999. Accordingly, DOE has issued a Supplement to the Draft EIS to address the most recent information on design evolution,

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including enhancements in design details and operating modes, and associated potential environmental impacts. DOE will provide the public an opportunity to comment on the Supplement and conduct hearings on the Supplement, as described below.

DATES: Comments on the Supplement to the Draft EIS will be accepted during a 45-day public comment period, which ends on June 25, 2001. DOE will consider comments submitted after June 25, 2001, to the extent practicable.

ADDRESSES: DOE will conduct public hearings on the Supplement in Amargosa Valley, Las Vegas, and Pahrump, Nevada. Public hearing locations and further details are provided below in this Notice under "Public Hearings and Invitation to Comment."

Written comments and requests for further information on the Supplement to the Draft EIS or the public hearings, and requests for copies of the document and included CD–ROM should be directed to: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

Written comments via facsimiles should include the following identifier: "Yucca Mountain Supplement to the Draft EIS." Addresses and locations where the Supplement will be available for public review are listed in this Notice under "Availability of the Supplement to the Draft EIS."

Electronic Format: Internet

Written comments on or requests for copies of the document may also be submitted over the Internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

FOR FURTHER INFORMATION CONTACT: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

For general information on the DOE NEPA process, contact: Ms. Carol M. Borgstrom, Director, Office of NEPA Policy and Compliance (EH–42), U.S. Department of Energy, 1000 Independence Ave., SW., Washington, DC 20585, Telephone 1–202–586–4600, or leave a message at 1–800–472–2756.

SUPPLEMENTARY INFORMATION: In August 1999, DOE issued the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Draft EIS), in accordance with the National Environmental Policy Act of 1969, as amended (42 U.S.C. 4321 *et seq.*), and the Nuclear Waste Policy Act, as amended (42 U.S.C. 10101 *et seq.*). The U.S. Environmental Protection Agency (EPA) issued a Notice of Availability (64 FR 44217) of the Draft EIS on August 13, 1999, initiating a public comment period that ended on February 28, 2000. During the 199-day comment period, DOE held 21 public hearings across the United States. The Draft EIS describes the Proposed Action to construct, operate and monitor, and eventually close a geologic repository for the disposal of spent nuclear fuel and high-level radioactive waste at Yucca Mountain. The Draft EIS also describes the potential environmental impacts associated with the Proposed Action.

For the Draft EIS, DOE based the analysis on the repository design described in the Viability Assessment of a Repository at Yucca Mountain. The Draft EIS discussed ongoing evaluations that could result in modifications to that design.

As DOE anticipated in the Draft EIS, repository design has continued to evolve. Although the fundamental aspects of the repository design have not changed from those discussed in the Draft EIS, design options and operating modes (ways in which to operate the repository) are being explored to reduce uncertainties and improve long-term repository performance and operational safety and efficiency. DOE has documented the evolution to date of its design efforts in the Yucca Mountain Science and Engineering Report: Technical Information Supporting Site Recommendation Consideration (YMS&ER), which describes the current design (which the Supplement calls the S&ER flexible design) and a range of possible repository operating modes. The YMS&ER also summarizes current technical information that the Secretary of Energy will use to determine whether to recommend approval of the Yucca Mountain site to the President for development as a repository.

Evaluations are underway to analyze the effect of various operating modes on repository performance. The flexible design discussed in the YMS&ER includes the ability to operate the repository in a range of operating modes that address higher and lower temperatures and associated humidity conditions. The higher-temperature operating mode means that at least a portion of the emplacement drift rock wall would have a maximum temperature above the boiling point of water at the elevation of the repository [96°C (205°F)]. Examples of the lower-temperature operating modes include conditions under which the drift rock wall temperatures would be below the boiling point of water, and conditions under which the waste package surface temperature would not exceed 85°C (185°F). To bound the impact analysis, DOE considered conditions under which the rock wall temperatures would be above the boiling point of water, and conditions under which waste package surface temperatures would not exceed 85°C.

DOE prepared the Supplement to update information presented in the Draft EIS. The Supplement evaluates potential environmental impacts that could occur, based on the design options and range of possible operating modes presented in the YMS&ER. The Supplement compares the impacts associated with the S&ER flexible design to the impacts presented in the Draft EIS.

The basis for the analytical scenarios presented in the Draft EIS was the amount of commercial spent nuclear fuel and its associated thermal output or load that DOE would emplace per unit area of the repository (called areal mass loading). In the Draft EIS, DOE evaluated three thermal load scenarios including high thermal load, a relatively high emplacement density of commercial spent nuclear fuel (85 metric tons of heavy metal (MTHM) per acre), intermediate thermal load (60 MTHM per acre), and low thermal load (25 MTHM per acre). The analytical scenarios described in the Draft EIS were not intended to place a limit on the choices among alternative designs because DOE expected that the repository design would continue to evolve. Rather, DOE selected these scenarios to represent the range of foreseeable design features and operating modes and to ensure that it considered the associated range of potential environmental impacts.

In contrast to focusing on thermal loads, the S&ER flexible design focuses on controlling the temperatures of the rock between the drifts, the waste package surfaces, and the drift walls to meet thermal management goals established for possible repository operating modes. To meet these thermal goals, the S&ER flexible design uses a linear thermal load (heat output per unit length of the emplacement drift) and emplaces waste packages relatively

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closer together than the Draft EIS design. Linear thermal load is expressed in terms of kilowatts per meter.

As with the thermal load analytical scenarios analyzed in the Draft EIS, the range of operating modes under the S&ER flexible design is representative of the range of foreseeable future design features and operating modes. The conservative estimates of the associated potential environmental impacts in the Supplement encompass or bound the potential impacts of foreseeable future repository design evolution.

The Supplement focuses on modifications to the repository design and operating modes addressed in the Draft EIS; it does not analyze aspects of the Proposed Action that have not been modified, such as the transportation of spent nuclear fuel and high-level radioactive waste, or the No-Action Alternative. DOE will address all aspects of the Proposed Action and the No-Action Alternative in the Final EIS. Because repository design has evolved from that considered in the Draft EIS, the Final EIS will evaluate only the S&ER flexible design, including the reasonable range of operating modes, and any enhancements to the flexible design developed as the result of ongoing analyses. DOE invites comments on its intention not to address the Draft EIS design in the Final EIS. DOE will respond to comments on the Draft EIS and on the Supplement in the Final EIS.

Public Hearings and Invitation to Comment

The public is invited to provide oral and written comments on the Supplement to the Draft EIS during the public comment period that ends on June 25, 2001. DOE will consider comments submitted during the comment period in preparation of the Final EIS. Comments submitted after June 25, 2001 will be considered to the extent practicable. DOE will hold public hearings to receive oral and written comments from members of the public at the following times and locations:

May 31, 2001: Longstreet Inn & Casino, Highway 373, Amargosa Valley, Nevada 89020; 5:00 pm–9:00 pm—Poster Session, 6:00 pm–9:00 pm—Hearing

June 5, 2001: Suncoast Hotel & Casino, 9090 Alta Drive, Las Vegas, Nevada 89144; 5:00 pm–9:00 pm—Poster Session, 6:00 pm–9:00 pm—Hearing

June 7, 2001: Bob Ruud Community Center, 150 North Highway #160, Pahrump, Nevada 89048; 5:00 pm–9:00 pm—Poster Session, 6:00 pm–9:00 pm—Hearing

This information will be available on the Yucca Mountain website at (*http://www.ymp.gov*) and on the toll-free information line at 1–800–967–3477.

Each of the public hearings will include a brief session in which an overview of the Supplement will be presented, a general question-and-answer session, and an opportunity to provide comments for the record. Members of the public who plan to present oral comments are asked to register in advance by calling 1–800–967–3477.

Availability of the Supplement to the Draft EIS

Copies of the Supplement are being distributed to Federal, State, and Indian tribal representatives, and other organizations and individuals who have indicated an interest in the EIS process. Copies of this document may be requested by calling 1–800–967–3477 or over the Internet via the Yucca Mountain Project website (*http://www.ymp.gov*). Both the Supplement and the Draft EIS will be available via the Internet on the DOE NEPA website at (*http://tis.eh.doe.gov/nepa*), under the listing DOE NEPA Analyses, or on the Yucca Mountain Project web site listed above. The availability of the Yucca Mountain Science and Engineering Report will be announced in a separate Federal Register Notice. That report will be available or can be requested on the Yucca Mountain Project website (*http://www.ymp.gov*) or by calling 1–800–967–3477.

Copies of references considered in preparation of the Supplement and Draft EIS, including the Yucca Mountain Science and Engineering Report, will be available at the following Public Reading Rooms: University of Nevada—Las Vegas, Nevada; University of NevadaÑ Reno, Nevada; Beatty Yucca Mountain Science Center, Nevada; Pahrump Yucca Mountain Science Center, Nevada; and the DOE Headquarters Office in Washington, D.C. Addresses of these Public Reading Rooms and of other Public Reading Rooms and libraries where the Supplement and the Draft EIS will be available for public review are listed below.

Public Reading Rooms

Inyo County—Contact: Andrew Remus; (760) 878–0447; Inyo County Yucca Mountain Repository Assessment Office; 168 North Edwards St.; Post Office Drawer L; Independence, CA 93526.

Oakland Operations Office—Contact: Laura Martinez; (510) 637–1762; U.S. Department of Energy Public Reading Room; EIC; 1301 Clay St., Room 700N; Oakland, CA 94612–5208.

National Renewable Energy Laboratory—Contact: John Horst; (303) 275–4709; Public Reading Room; 1617 Cole Blvd.; Golden, CO 80401.

Rocky Flats Public Reading Room—Contact: Gary Morrell; (303) 469–4435; College Hill Library; 3705 112th Ave. B121; Westminster, CO 80030.

Headquarters Office—Contact: Carolyn Lawson; (202) 586–3142; U.S. Department of Energy; Room 1E–190, Forrestal Building; 1000 Independence Ave., SW; Washington, DC 20585.

Atlanta Support Office—Contact: Nancy Mays/Laura Nicholas; (404) 347–2420; Department of Energy; Public Reading Room; 730 Peachtree St., Suite 876; Atlanta, GA 30308–1212.

Southeastern Power Administration—Contact: Joel W. Seymour; (706) 213–3800; U.S. Department of Energy; Reading Room; Samuel Elbert Building; 2 South Public Square; Elberton, GA 30635–2496.

Boise State University Library—Contact: Adrien Taylor; (208) 426–1737; Government Documents; 1910 University Dr.; P.O. Box 46; Boise, ID 83707–0046.

Idaho Operations Office—Contact: Brent Jacobson; (208) 526–1144; Public Reading Room; 1776 Science Center Dr.; Idaho Falls, ID 83402.

Chicago Operations Office—Contact: John Shuler; (312) 996–2738; Document Department; University of Illinois at Chicago; 801 South Morgan St.; Chicago, IL 60607.

Strategic Petroleum Reserve Project Management Office—Contact: Deanna Harvey; (504) 734–4316; U.S. Department of Energy; SPRPMO/SEB Reading Room; 850 Commerce Road, East; New Orleans, LA 70123.

Lander County—Contact: Mickey Yarbo; (775) 635–2882; 315 S. Humboldt St.; Battle Mountain, NV 89820.

Beatty Yucca Mountain Science Center—Contact: Marina Anderson; (775) 553–2130; 100 North E Ave.; Beatty, NV 89003.

Lincoln County—Contact: Jason Pitts; (775) 726–3511; Box 1068; 176 Clover St.; Caliente, NV 89008.

Nevada State Clearinghouse—Contact: Heather Elliot; (775) 684–0209; Department of Administration; 209 E. Musser Street, Room 200; Carson City, NV 89701.

White Pine County—Contact: Josie Larson; (775) 289–2033; 959 Campton St.; Ely, NV 89301.

Eureka County—Contact: Leonard Fiorenzi; (775) 237–5372; 701 S. Main St.; (P.O. Box 714); Eureka, NV 89316.

Churchill County—Contact: Alan Kalt; (775) 423–5136; 155 North Taylor St., Suite 182; Fallon, NV 89046–2478.

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Esmeralda County—Contact: George McCorkell; (775) 485–3419; Repository Oversight Program; 233 Crook St.; P.O. Box 295; Goldfield, NV 89316.

Mineral County—Contact: Judy Shankle; (775) 945–2484; First & A Streets; (*Hand Deliverables Only*); (P.O. Box 1600); Hawthorne, NV 89415.

Clark County—Contact: Dennis Bechtel; (702) 455–5178; 500 South Grand Central Parkway #3012; (P.O. Box 551751); Las Vegas, NV 89155–1751.

Las Vegas, Nevada—Contact: Reference Desk; (702) 895–3409; University of Nevada Las Vegas; James R. Dickinson Library; Government Publications; 4505 Maryland Parkway; Las Vegas, NV 89154–7013.

Las Vegas Yucca Mountain Science Center—Contact: Claire Whetsel; (702)295–1312; 4101-B Meadows Lane; Las Vegas, NV 89107.

Nye County—Contact: Les Bradshaw; (775) 727–7727; c/o Department of Natural Resources and Federal Facilities; 1210 E. Basin Ave., Suite 6; Pahrump, NV 89048.

Pahrump Yucca Mountain Science Center—Contact: John Pawlak; (775) 727–0896; 1141 South Highway 160; Pahrump NV, 89041.

Reno, Nevada—Contact: Kathie Brinkerhoff; (775) 784–6500; University of Nevada, Reno; The University of Nevada Libraries; Business and Government Information Center M/S 322; 1664 N. Virginia St.; Reno, NV 89557–0044.

Albuquerque Operations Office—Contact: Dan Berkley; (505) 277–7180; U.S. DOE Contract Reading Room; University of New Mexico; Zimmerman Library; Albuquerque, NM 87131–1466.

Fernald Area Office—Contact: Diane Rayer;(513)648–7480; U.S. Department of Energy; Public Information Room;10995 Hamilton-Cleves Highway M/S 78; Harrison, OH 45030.

Southwestern Power Administration—Contact: Marti Ayres; (918) 595–6609; U.S. Department of Energy; Public Reading Room; 1 West 3rd, Suite 1600; Tulsa, OK 74103.

Bonneville Power Administration—Contact: Bill Zimmerman/Darlene Freestad; (503) 230–7334; U.S. Department of Energy; BPA–C–ACS–1; 905 NE 11th St.; Portland, OR 97232.

Pittsburgh Energy Technology Center—Contact: Ann C. Dunlap; (412) 386–6167; U.S. Department of Energy; Building 922/M210; Cochrans Mill Rd.; Pittsburgh, PA 15236–0940.

Savannah River Operations Office—Contact: Pauline Connell; (803) 725–2497; Gregg-Graniteville Library; University of South Carolina-Aiken; 171 University Parkway; Aiken, SC 29801.

University of South Carolina—Contact: William Suddeth; (803) 777–4841; Thomas Cooper Library; Documents/Microforms Department; Green and Sumter Streets; Columbia, SC 29208.

Oak Ridge Operations Office—Contact: Walter Perry; (865) 241–4780; U.S. Department of Energy; Public Reading Room; P.O. Box 2001; American Museum of Science and Energy; 230 Warehouse Rd.; Oak Ridge, TN 37831.

Southern Methodist University—Contact: Stephen Short; (214) 768–2561; Central Union Libraries Fondren Library; Government Information; Airline and McFarland Streets; Dallas, TX 75275–0135.

University of Utah—Contact: Walter Jones; (801) 581–8863; Marriott Library Special Collections; 295 South 15th East; Salt Lake City, UT 84112–0860.

Richland Operations Center—Contact: Terri Traub; (509) 372–7443; U.S. Department of Energy; Public Reading Room; 2770 University Drive; Room 101L; PO Box 999; Mailstop H2–53; Richland, WA 99352.

Issued in Washington, DC, April 27, 2001.

Lake Barrett,

Acting Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 01–11275 Filed 5–3–01; 8:45 am]

BILLING CODE 6450–01–P

33534 Federal Register / Vol. 66, No. 121 / Friday, June 22, 2001 / Notices

DEPARTMENT OF ENERGY

Comment Period Extension for Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Department of Energy (DOE).

ACTION: Notice of comment period extension.

SUMMARY: On May 4, 2001, the U.S. Department of Energy (DOE) published a Notice of Availability (66 FR 22540) of its Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Draft EIS) (DOE/EIS–0250D–S) and announced a 45-day public comment period ending June 25, 2001. In response to requests from the public, DOE is extending the comment period to July 6, 2001.

DATES: Comments on the Supplement to the Draft EIS are now due by July 6, 2001. DOE will consider all comments received during the comment period in preparation of the Final EIS. Comments received after July 6, 2001 will be considered to the extent practicable.

ADDRESSES: Written comments and requests for further information on the Supplement to the Draft EIS, and requests for copies of the document (hard copy or CD–ROM) should be directed to: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

Written comments via facsimiles should include the following identifier: "Yucca Mountain Supplement to the Draft EIS."

Written comments on or requests for copies of the document may also be submitted over the internet via the Yucca Mountain Project website at *http://www.ymp.gov*, under the listing "Environmental Impact Statement."

FOR FURTHER INFORMATION CONTACT: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

For general information on the DOE NEPA process, contact: Ms. Carol M. Borgstrom, Director, Office of NEPA Policy and Compliance (EH–42), U.S. Department of Energy, 1000 Independence Avenue, SW., Washington, DC 20585, Telephone 1–202–586–4600, or leave a message at 1–800–472–2756.

Issued in Washington, DC, June 18, 2001.

Ronald Milner,

Chief Operating Officer, Office of Civilian Radioactive Waste Management.

[FR Doc. 01–15682 Filed 6–21–01; 8:45 am]

BILLING CODE 6450–01–U

Federal Register / Vol. 66, No. 126 / Friday, June 29, 2001 / Notices 34623

DEPARTMENT OF ENERGY

Comment Period for Specific Individuals for the Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, NV

AGENCY: Department of Energy (DOE).

ACTION: Notice of comment period for specific individuals.

SUMMARY: On May 4, 2001, the U.S. Department of Energy (DOE) published a Notice of Availability (66 FR 22540) of its Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Draft EIS) (DOE/EIS–0250D–S) and announced a 45-day public comment period ending June 25, 2001. In response to requests from the public, DOE extended the comment period to July 6, 2001 (66 FR 33534). DOE has discovered that some individuals had requested and received a copy of the Draft EIS, but were not sent the Supplement to the Draft EIS. DOE has now distributed the Supplement to those individuals, and will accept comments from those individuals transmitted or postmarked by August 13, 2001.

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DATES: Comments from specific individuals who received a copy of the Supplement with a June 22, 2001 letter from DOE regarding this oversight are now due by August 13, 2001. DOE will consider all comments received from those individuals by that date in preparing the Final EIS. Comments received from those individuals after August 13, 2001 will be considered to the extent practicable.

ADDRESSES: Written comments and requests for further information on the Supplement to the Draft EIS, and requests for copies of the document (hard copy or CD–ROM) should be directed to: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

Written comments via facsimiles should include the following identifier: "Yucca Mountain Supplement to the Draft EIS."

Written comments on or requests for copies of the document may also be submitted over the internet via the Yucca Mountain Project website at http://www.ymp.gov, under the listing "Environmental Impact Statement."

FOR FURTHER INFORMATION CONTACT: Dr. Jane Summerson, EIS Document Manager, M/S 010, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Office, P.O. Box 30307, North Las Vegas, Nevada 89036–0307, Telephone 1–800–967–3477, Facsimile 1–800–967–0739.

For general information on the DOE NEPA process, contact: Ms. Carol M. Borgstrom, Director, Office of NEPA Policy and Compliance (EH–42), U.S. Department of Energy, 1000 Independence Avenue, SW., Washington, DC 20585, Telephone 202–586–4600, or leave a message at 1–800–472–2756.

Issued in Washington, DC, June 25, 2001.

Lake Barrett,

Acting Director, Office of Civilian Radioactive Waste Management.

[FR Doc. 01–16420 Filed 6–28–01; 8:45 am]

BILLING CODE 6450–01–P

Appendix C

Interagency and Intergovernmental Interactions

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APPENDIX C. INTERAGENCY AND INTERGOVERNMENTAL INTERACTIONS

In the course of producing this environmental impact statement (EIS), the U.S. Department of Energy (DOE) has interacted with a number of governmental agencies and other organizations. These interaction efforts have several purposes, as follows:

- Discuss issues of concern with organizations having an interest in or authority over land that the Proposed Action (to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain) would affect directly, or organizations having other interests that some aspect of the Proposed Action could affect.
- Obtain information pertinent to the environmental impact analysis of the Proposed Action.
- Initiate consultations or permit processes, including providing data to agencies with oversight, review, or approval authority over some aspect of the Proposed Action.
- Provide information relevant to the development of responses to public comments on the Draft EIS and the Supplement to the Draft EIS.

Section C.1 summarizes the interactions. DOE has completed several efforts and will complete all required consultations before publishing the Final EIS. Section C.2 describes interests held by agencies and organizations involved in consultations and other interactions.

C.1 Summary of Activity

Table C-1 lists organizations with which DOE has initiated interaction processes concerning the proposed Yucca Mountain Repository. This table summarizes the authority of or interest of the listed organizations and the status of those interactions.

C.2 Interests of Selected Agencies and Organizations with which DOE Has Held Consultations or Informational Exchanges Regarding the Yucca Mountain Repository Proposal

Regulations that establish a framework for interactions include 40 CFR 1502.25, which provides for consultations with agencies having authority to issue applicable licenses, permits, or approvals, or to protect significant resources, and 10 CFR 1021.341(b), which provides for interagency consultations as necessary or appropriate.

C.2.1 FEDERAL AGENCIES

C.2.1.1 Bureau of Land Management

The Bureau of Land Management has a range of interests potentially affected by the Proposed Action. The Bureau, as a part of the U.S. Department of the Interior:

- Controls a portion of the land that would need to be withdrawn by Congress to accommodate the proposed repository

Table C-1. Organizations with which DOE has initiated interactions (page 1 of 5).

FEDERAL AGENCIES		
Organization	Authority/interest	Interactions
Bureau of Land Management	Controls part of land required for repository. Controls portions of lands in Nevada that transportation corridors cross. Has responsibility for management and use of lands it controls, including management of habitat and species. Has data on topography, habitat, species, and other topics on land it controls.	DOE provided a briefing on the EIS. DOE and BLM held a subsequent meeting to ensure understanding of comments on the Draft EIS and the Supplement to the Draft EIS.
Council on Environmental Quality	Oversees the National Environmental Policy Act process	DOE provided information and NEPA process products, including the Draft EIS and the Supplement to the Draft EIS, to assist CEQ in its oversight responsibility. DOE provided a briefing on the Draft EIS and the Supplement to the Draft EIS, including background information, schedule, and an update on the repository design.
National Marine Fisheries Service	Oversees compliance with Marine Protection Research and Sanctuaries Act and, for some species, with the Endangered Species Act.	DOE informally consulted with the National Marine Fisheries Service on possible effects of barging on threatened and endangered marine species. Endangered Species Act compliance information was requested. Project activities and National Marine Fisheries Service jurisdiction were discussed. DOE has completed activities required for marine species under the Endangered Species Act.
National Park Service	Potential for proposal to affect water supply in Death Valley region. Effect of any water appropriation required for repository, EIS status, and approach to EIS development.	DOE and NPS discussed NPS concerns about use of water for repository construction and operation.
Naval Nuclear Propulsion Program	The Naval Nuclear Propulsion Program is a joint U.S. Navy and DOE organization responsible for management of naval spent nuclear fuel.	DOE has conducted ongoing dialogue and information exchange on the EIS status and the DOE framework.
Nuclear Waste Technical Review Board	Provides technical and scientific expertise in the evaluation of program activities related to site characterization and the packaging, transportation, and disposal of spent nuclear fuel and high-level radioactive waste.	DOE has provided information and work products to the Board, has met with the Board to review aspects of site characterization and the suitability determination, and has received scientific and technical recommendations from the Board. DOE provided a briefing on the Draft EIS and the Supplement to the Draft EIS, including background information, schedule, and an update on the repository design. DOE also provided opportunities for public involvement in some of its interactions with the Board.

Table C-1. Organizations with which DOE has initiated interactions (page 2 of 5).

FEDERAL AGENCIES		
Organization	Authority/interest	Interactions
U.S. Air Force	Controls part of land being considered for withdrawal for repository (on the Nellis Air Force Range) and for one Nevada rail implementing alternative and one heavy-haul truck implementing alternative. Has identified security concerns over potential development of the Nevada rail and heavy-haul truck implementing alternatives that would pass through land it controls.	DOE provided a briefing on the process for this EIS and on the range of issues being analyzed. DOE and USAF personnel held informal meetings to discuss specific issues and update EIS status. The USAF provided a statement of its concerns about certain transportation alternatives DOE is considering.
U.S. Army Corps of Engineers	Has authority over activities that discharge dredge or fill material into waters of the United States.	The two agencies discussed strategies for minimizing impacts and obtaining permits for waters of the United States.
U.S. Department of Agriculture	Responsible for protection of prime farm lands for agriculture in areas potentially affected by the Proposed Action.	Letter exchange resolved issues regarding repository's potential effect on farmlands. Need for additional interaction is uncertain.
U.S. Department of the Interior	Has responsibility for most public lands and natural resources, Indian Affairs, and geological resources, and trust responsibility with respect to American Indians.	DOE and DOI held a meeting to ensure understanding of comments on the Draft EIS and the Supplement to the Draft EIS. Attendees included representatives from the Bureau of Land Management, Fish and Wildlife Service, National Park Service, and the U.S. Geological Survey.
U.S. Department of Transportation	Has regulatory authority over transportation of nuclear and hazardous waste materials, including packaging design, manufacture and use, pickup, carriage, and receipt, and highway route selection.	EIS status briefing has been provided. DOE and DOT have held informal discussions concerning modeling techniques and analytical methods DOE is using in its evaluation of transportation issues.
U.S. Environmental Protection Agency	Has regulatory authority over radiological standards and groundwater protection standards. Mandatory role in review of EIS adequacy.	DOE provided a briefing on its approach to the EIS and on scope and content. EPA described its EIS rating process. The two agencies discussed methods for addressing any EIS comments that EPA might submit. DOE also provided a briefing on the Draft EIS and the Supplement to the Draft EIS.
U.S. Fish and Wildlife Service	Oversees compliance with the Endangered Species Act for some species and compliance with the Fish and Wildlife Coordination Act.	DOE and FWS have held discussions and exchanged species list information pursuant to the Endangered Species Act. DOE submitted a Draft Biological Assessment to the FWS, which issued a Final Biological Opinion that sets forth the measures, terms, and conditions for protection of the desert tortoise.

Table C-1. Organizations with which DOE has initiated interactions (page 3 of 5).

FEDERAL AGENCIES		
Organization	Authority/interest	Interactions
U.S. Nuclear Regulatory Commission	Has licensing authority over spent nuclear fuel and high-level radioactive waste geologic repositories. Is required by NWPA to adopt Yucca Mountain Repository EIS to the extent practicable with the issuance by NRC of any construction authorization and license for a repository. Has regulatory authority over commercial nuclear power plants, storage of spent nuclear fuel at commercial sites, and packaging for transportation of spent nuclear fuel and high-level radioactive waste. Has general authority over possession and transfer of radioactive material.	Discussions have been held on the purpose and need for the action and on the status of the EIS. Numerous interactions related to the potential repository program. An EIS technical exchange was conducted.

STATES AND STATE AGENCIES		
Organization	Authority/interest	Interactions
California Energy Commission	Knowledge of major projects; jurisdiction over aspects of California projects.	DOE provided the Draft EIS distribution list
Nevada State Legislators	Adequacy of Nevada legal structure; passage of legislation	DOE provided an update on the status of the project
State of Nevada Department of Transportation	Has authority over transportation and highways in Nevada.	DOE and NDOT personnel have informally discussed Nevada transportation issues. The State of Nevada received a formal briefing on the Draft EIS and the Supplement to the Draft EIS.
Affected units of local government	Local governments with general jurisdiction over regions or communities that could be affected by implementation of the Proposed Action.	Meetings that include discussions, information exchange, and status briefings, discussion of the OCRWM program, and briefings on the Draft EIS and the Supplement to the Draft EIS and on the process for developing responses to comments on the Draft EIS and the Supplement to the Draft EIS.

Table C-1. Organizations with which DOE has initiated interactions (page 4 of 5).

FEDERAL AND STATE AGENCIES CONSULTED JOINTLY		
Organization	Authority/interest	Interactions
Advisory Council on Historic Preservation and Nevada State Historic Preservation Officer	Protection and preservation of historic properties and cultural resources of importance to Native Americans and others. Administration of the National Historic Preservation Act and of regulatory requirements supporting that act.	Following discussions among DOE, the Advisory Council on Historic Preservation, and the Nevada State Historic Preservation Officer, DOE and the Advisory Council on Historic Preservation have entered into a programmatic agreement (DIRS 104558-DOE 1988, all) establishing procedures DOE is to follow during site characterization and during the Secretary of Energy's development of a repository site recommendation. The Advisory Council on Historic Preservation indicated that it would be available to assist DOE in complying with environmental review requirements for historic properties.
LOCAL AGENCIES		
Organization	Authority/interest	Interactions
Clark County Desert Conservation Program	Projects potentially affecting desert in Clark County	DOE presented a briefing on Draft EIS studies and measures related to desert tortoise
Clark County Emergency Planning Committee	Projects that could require emergency planning	DOE presented information on the status of EIS
NATIVE AMERICAN ORGANIZATIONS		
Organization	Authority/interest	Interactions
National Indian Nuclear Waste Policy Committee	Nuclear waste projects that could affect tribes	DOE presented information on the status of the EIS
Native American Tribes	Have concern for potential consequences of repository development and transportation activities on cultural resources, traditions, and spiritual integrity of the land. Have governmental status. All interactions required for the American Indian Religious Freedom Act, the Native American Graves Protection and Repatriation Act, and the National Historic Preservation Act are being accomplished.	Ongoing discussions on a range of topics at least twice per year. Tribal representatives have prepared and submitted the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (DIRS 102043-AIWS 1998, all). DOE held formal meetings to present the Draft EIS and the Supplement to the Draft EIS. Formal comments were taken from participants at both meetings.

Table C-1. Organizations with which DOE has initiated interactions (page 5 of 5).

NONGOVERNMENTAL ORGANIZATIONS		
Organization	Authority/interest	Interactions
Advisory Committee on Nuclear Waste	Advisory committee to Nuclear Regulatory Commission on nuclear waste issues	DOE submitted reports on project status, Draft EIS, and Supplement to the Draft EIS, including background information, schedule, update on repository design, and public involvement opportunities.
Commission on Nuclear Projects	Knowledge of DOE activities	Briefing on Draft EIS
Community Advisory Board for the Nevada Test Site	Maintaining awareness of relationships between NTS and the Yucca Mountain repository proposal	Briefings on Draft EIS, Supplement to the Draft EIS, EIS schedule, and project activities.
Community Advisory Board, Idaho National Engineering and Environmental Laboratory	Relationship between Idaho National Engineering and Environmental Laboratory and proposed Yucca Mountain repository	DOE discussed relationship between Idaho National Engineering and Environmental Laboratory and the potential repository
Institute of Nuclear Materials Management	Activities involving nuclear materials	DOE presented information on the Draft EIS status
Interjurisdictional Committee from San Onofre Nuclear Generating Stations	Projects potentially related to San Onofre	DOE made a presentation on transportation issues to the Decisionmakers' Symposium of the Interjurisdictional Committee from San Onofre Nuclear Generating Stations
National Academy of Sciences	Congressionally assigned responsibility to study aspects of repository proposal	DOE presented information on work performed for DOE as part of EIS
National Conference of State Legislators	Knowledge of major projects	Provision of information on potential impacts from proposed repository
Nuclear Energy Institute	Knowledge of DOE activities	DOE answered questions from senior project manager for spent fuel management
Rotary Clubs of Las Vegas	Projects that could affect Las Vegas	DOE provided an update on the status of the project

a. Abbreviations: BLM = Bureau of Land Management; CEQ = Council on Environmental Quality; DOE = U.S. Department of Energy; DOI = Department of the Interior; DOT = Department of Transportation; EIS = Environmental Impact Statement; EPA = Environmental Protection Agency; FWS = Fish and Wildlife Service; NDOT = State of Nevada Department of Transportation; NEPA = National Environmental Policy Act; NPS = National Park Service; NRC = Nuclear Regulatory Commission; NTS = Nevada Test Site; NWPA = Nuclear Waste Policy Act; OCRWM = Office of Civilian Radioactive Waste Management; USAF = United States Air Force.

- Controls portions of land in Nevada in the five corridors for a potential branch rail line and along the five potential routes for heavy-haul trucks
- Has responsibility for wild horse and wild burro management areas (Public Law 92-195, as amended, Section 3; 43 CFR Part 2800) and wildlife management areas (43 CFR 24.4) in Nevada that alternative rail corridors and routes for heavy-haul trucks cross
- Has power to grant rights-of-way and easements for transportation routes across lands it controls

The Bureau of Land Management would have a continuing interest in the development of a repository at Yucca Mountain and associated transportation routes in the State of Nevada. Any comments from the Secretary of the Interior on the EIS must be included in the Secretary of Energy's recommendations to the President on the Yucca Mountain site.

Interaction

DOE provided a briefing to the Bureau of Land Management on the status of the Draft EIS, and subsequently met with the Bureau to ensure understanding of comments on the Draft EIS and the Supplement to the Draft EIS.

C.2.1.2 Fish and Wildlife Service

The Fish and Wildlife Service, a bureau of the U.S. Department of the Interior, has a role in the overall evaluation of the impacts from the Proposed Action under consideration in the repository EIS. Under the Endangered Species Act of 1973, as amended, the Fish and Wildlife Service has responsibility to determine if projects such as the proposed Yucca Mountain Repository would have an adverse impact on endangered or threatened species, on species proposed for listing or on designated critical habitat. Any comments from the Secretary of the Interior on the EIS must accompany the Secretary of Energy's recommendation to the President on the Yucca Mountain site.

No endangered or proposed species occur on lands that would be needed for the repository. The desert tortoise is the only threatened species known to exist on this land, which lies at the northern edge of the range for desert tortoises (DIRS 104618-Buchanan 1997, pp. 1 to 4). The repository would not need or impact any critical habitat.

To evaluate the potential for the proposed repository to affect the desert tortoise, DOE and the Fish and Wildlife Service have followed a process that, in summary, includes three steps:

1. DOE submitted a study (biological assessment) containing information on desert tortoise activities and habitat in the vicinity of the proposed project, a description of project activities that could affect the desert tortoise, and the potential for adverse impacts to desert tortoises or habitat. Based on this information, DOE made a determination on whether the project would result in adverse impacts to the species.

2. DOE and the Fish and Wildlife Service met as necessary to discuss details of the potential for interaction between desert tortoises and project activities, and to consider appropriate protective measures DOE could take to reduce the potential for project impact to desert tortoises.

3. The Fish and Wildlife Service issued a biological opinion that states its opinion on whether the proposed project may proceed without causing adverse impacts to the desert tortoise, jeopardizing the continued existence of the species, or resulting in harassment, harm, or death of individual animals. The biological opinion contains protective measures and conditions that DOE would have to implement during construction, operation and monitoring, and closure of the proposed repository to minimize

adverse impacts and the potential for tortoise deaths. The biological opinion is included in the Final EIS as Appendix O.

DOE, which has conducted site characterizations at Yucca Mountain since 1986, and the Fish and Wildlife Service have conducted previous consultation processes that addressed the potential for site characterization activities to affect the desert tortoise. These processes resulted in biological opinions, published in 1990 and 1997, that determined that site characterization activities could proceed without unacceptable harm to the desert tortoise and that the protective measures and conditions stated in the biological opinions should apply to DOE activities. None of the proposed repository land is critical habitat for tortoises. The most recent consultation process on the desert tortoise built on the information gathered and the practices developed in the previous consultations, and on the positive results obtained.

Interaction

Discussions have been held and species list information has been obtained. Discussion topics have included Endangered Species Act compliance issues and agreement on extension of time for completion of the Biological Assessment. DOE submitted a Biological Assessment to the Fish and Wildlife Service. The Fish and Wildlife Service issued a Biological Opinion that contains measures, terms, and conditions for protecting the desert tortoise.

C.2.1.3 Naval Nuclear Propulsion Program

The Naval Nuclear Propulsion Program is a joint U.S. Navy and DOE program responsible for all matters pertaining to naval nuclear propulsion (DIRS 101941-USN 1996, p. 2-2). This program is responsible for the nuclear propulsion plants aboard more than 82 nuclear-powered warships with more than 102 reactors and for nuclear propulsion work performed at four naval shipyards and two private shipyards. It is also responsible for two government-owned, contractor-operated laboratories, two moored training ships, two land-based prototype reactors, and the Expended Core Facility at the Naval Reactors Facility at the Idaho National Engineering and Environmental Laboratory.

The Naval Nuclear Propulsion Program manages naval spent fuel after its withdrawal from nuclear-powered warships and prototype reactors at the Expended Core Facility. The program has conducted studies and performed environmental impact analyses on the management and containerization of naval spent nuclear fuel to prepare it for shipment to the proposed repository or other spent fuel management system (DIRS 101941-USN 1996, all). Information from these studies is relevant to the containerization of other spent nuclear fuel that could be shipped to the proposed repository.

Interaction

Since the beginning of preparations for this EIS, the Naval Nuclear Propulsion Program has participated in quarterly meetings with DOE to discuss information relevant to the emplacement of naval spent nuclear fuel in a monitored geologic repository. Detailed information about naval spent nuclear fuel is classified; therefore, the Naval Nuclear Propulsion Program performed a parallel set of thermal, nuclear, and dose calculations and provided unclassified results to DOE for inclusion in this EIS. In some cases DOE used those results as input parameters for additional analyses. Representatives of the program participated throughout the review process to ensure the accurate presentation of information on naval spent nuclear fuel.

C.2.1.4 National Marine Fisheries Service

The National Marine Fisheries Service exercises protective jurisdiction over aspects of the marine environment, including research activities, marine sanctuaries, and certain species protected by the Endangered Species Act. Potential DOE actions associated with transportation to the repository (for example, barging and construction or modification of bridges and docking facilities) could require interaction with the National Marine Fisheries Service.

Interaction

DOE participated in informal discussions that identified National Marine Fisheries Service jurisdiction relevant to the Yucca Mountain Project and potential project activities of jurisdictional interest to the National Marine Fisheries Service in fulfilling its responsibilities. DOE has completed activities required under the Endangered Species Act for National Marine Fisheries Service jurisdictional species.

C.2.1.5 National Park Service

The National Park Service, which is a bureau of the U.S. Department of the Interior, is responsible for the management and maintenance of the Nation's national parks and monuments. The implementation of the Proposed Action could potentially affect the water supply in Death Valley National Park, which is downgradient from Yucca Mountain. The National Park Service, therefore, would have an interest in any water appropriation granted to DOE for the repository. In addition, the Park Service has expressed its interest in this EIS, its status, and the approach DOE has followed in developing the EIS.

Interaction

DOE and National Park Service representatives held a discussion during which they addressed Park Service concerns about water use for repository construction and operation. The discussion resulted in satisfaction of National Park Service concerns.

C.2.1.6 U.S. Air Force

The U.S. Air Force operates Nellis Air Force Base northeast of Las Vegas, and the Nevada Test and Training Range (formerly called the Nellis Air Force Range), which occupies much of south-central Nevada. The Range is an important facility for training American and Allied combat pilots and crews (DIRS 103472-USAF 1999, pp. 1-1 and 1-3).

A portion of the land being considered for withdrawal for the proposed repository is on the Nellis Range. If the land were withdrawn and development of the proposed repository proceeded, the Air Force would hold a continuing interest in the potential for construction, operation and monitoring, and closure activities at the repository to have consequences for Air Force operations on the adjoining land.

The Nellis Air Force Range is a premier location for training of operational flying units, as well as for conducting developmental and operational testing of advanced weapons systems. The Nellis Range complex consists of extensive air and ground working areas, live ordnance impact areas, and an extensive array of instrumental threat simulators. The Range maintains a heavy volume of testing and training activities on a daily basis. One potential Nevada branch rail line and one potential Nevada heavy-haul truck route that DOE has evaluated in this EIS would pass through the Nellis Range.

Interaction

DOE provided a briefing for U.S. Air Force personnel on the process DOE is following for this EIS and on the range of issues being analyzed. DOE and Air Force personnel have held informal meetings to discuss specific issues.

The U.S. Air Force has communicated to DOE that the transportation of spent nuclear fuel and high-level radioactive waste through the Nellis Range would inevitably lead to the imposition of flight restrictions, and that such restrictions would severely degrade the U.S. Air Force's ability to test existing and evolving weapons systems, or to train U.S. and allied aircrews. In addition, the Air Force maintains that there is no route through the Range that could avoid adversely affecting classified national security activities.

C.2.1.7 U.S. Army Corps of Engineers

The Clean Water Act of 1977 (42 U.S.C. 1251 *et seq.*) gives the U.S. Army Corps of Engineers permitting authority over activities that discharge dredge or fill material into waters of the United States. If DOE activities associated with a repository at Yucca Mountain discharged dredge or fill into any such waters, DOE could need to obtain a permit from the Corps. The construction or modification of rail lines or highways to the repository would also require Section 404 permits if those actions included dredge and fill activities or other activities that would discharge dredge or fill into waters of the United States. DOE has obtained a Section 404 permit for site characterization-related construction activities it might conduct in Coyote Wash or its tributaries or in Fortymile Wash.

Interaction

DOE and the Corps of Engineers have discussed strategies for minimizing impacts to any waters of the United States and have reviewed procedures for obtaining permits in the event that DOE activities could result in discharge of dredge or fill to the waters of the United States.

C.2.1.8 U.S. Department of Agriculture

The U.S. Department of Agriculture has the responsibility to ensure that the potential for Federal programs to contribute to unnecessary and irreversible conversion of farmlands to nonagricultural uses is kept to a minimum. Proposed Federal projects must obtain concurrence from the Natural Resource Conservation Service of the Department of Agriculture that potential activities would not have unacceptable effects on farmlands (7 U.S.C. 4201 *et seq.*).

Interaction

DOE has submitted documentation to the Department of Agriculture on potential consequences of the Proposed Action for farmlands. The Department of Agriculture has reviewed the documentation and the two agencies have agreed that a repository at Yucca Mountain would not affect farmlands.

C.2.1.9 U.S. Department of the Interior

The U.S. Department of the Interior has responsibility for most nationally owned public lands and natural resources. Department of the Interior activities potentially affected by the Proposed Action include managing lands and resources, conducting scientific research and investigations, developing resources, and carrying out trust responsibilities of the U.S. Government with respect to American Indians. The Department of the Interior oversees various bureaus with jurisdictional responsibilities or interests affected by Yucca Mountain: The Bureau of Indian Affairs, the Bureau of Land Management, the National Park Service, the Office of Surface Mining, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey. In addition to meeting with the Department of the Interior itself, DOE has contacted several of the bureaus separately regarding Yucca Mountain.

Interaction

DOE met jointly with the Department of the Interior and several of its bureaus (Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, U.S. Geological Survey) to ensure understanding of comments made on the Draft EIS and the Supplement to the Draft EIS.

C.2.1.10 U.S. Department of Transportation

The U.S. Department of Transportation has the authority to regulate several aspects of the transportation of spent nuclear fuel and high-level radioactive waste to the proposed Yucca Mountain Repository. The general authority of the Department of Transportation to regulate carriers and shippers of hazardous materials includes packaging procedures and practices, shipping of hazardous materials, routing, carrier operations, equipment, shipping container construction, and receipt of hazardous materials (49 U.S.C. 1801; 49 CFR Parts 171 through 180).

Interaction

DOE and the Department of Transportation have exchanged letters and informal communications on topics pertaining to the proposed Yucca Mountain Project that are within the Department of Transportation's regulatory interest. DOE and the Department of Transportation have held informal discussions on the modeling techniques and analytical methods DOE used in its evaluation of transportation issues.

C.2.1.11 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency has two primary responsibilities in relation to the proposed Yucca Mountain Repository. It is responsible for promulgating regulations that set radiological protection standards for media that would be affected if radionuclides were to escape the confinement of the repository. In addition, the Agency oversees the National Environmental Policy Act process for Federal EISs. Council on Environmental Quality regulations implementing the National Environmental Policy Act specify procedures that agencies must follow and actions that agencies must take in preparing EISs. Depending on the level of concern that the Agency might have with environmental aspects of the Yucca Mountain Project Draft EIS, it can initiate a consultation between DOE and the Council on Environmental Quality. Under the Nuclear Waste Policy Act, as amended (NWPA), the Secretary of Energy's recommendation to the President must include both a Final EIS and the Environmental Protection Agency's comments on the EIS.

Interaction

DOE and the Environmental Protection Agency held a meeting at which DOE provided a briefing on its approach to the EIS and its scope and content. At that meeting, the Environmental Protection Agency described its EIS rating process, and personnel from the two agencies discussed methods for addressing EIS comments that the Agency submitted on the Draft EIS.

In addition, DOE provided a briefing to the Environmental Protection Agency on the Draft EIS and the Supplement to the Draft EIS. The briefing included information on schedule, update of the repository design, and opportunities provided for public involvement during the EIS preparation process.

C.2.1.12 U.S. Nuclear Regulatory Commission

The Nuclear Waste Policy Act, as amended (42 U.S.C. 10101 *et seq.*), establishes a multistep procedure for reviews and decisions on the proposal to construct, operate and monitor, and close a geologic repository at Yucca Mountain. The final steps in this procedure require DOE to make an application to the Nuclear Regulatory Commission for authorization to construct a repository at Yucca Mountain and the Commission to consider this information and make a final decision within 3 years on whether to approve the application. The NWPA directs the Commission to adopt this EIS to the extent practicable in support of its decisionmaking process. Any Nuclear Regulatory Commission comment on this EIS must accompany the Secretary of Energy's recommendation to the President.

The Nuclear Regulatory Commission also has authority under the Atomic Energy Act of 1954, as amended, to regulate persons authorized to own, possess, or transfer radiological materials. In addition, the Commission regulates transportation packaging, transportation operations, and the design, manufacture, and use of shipping containers for radiological materials with levels of radioactivity greater than Department of Transportation Type A materials. Determination as to whether radiological materials are Type A or greater are made in accordance with a procedure set forth in 49 CFR 173.431.

Interaction

Discussions have been held on the purpose and need for the Proposed Action and on the status of the EIS. The regulatory context of the EIS has been reviewed. Additional discussions have been related to the repository program in general or to specific informational items. An EIS technical exchange was conducted. Further interactions with the Nuclear Regulatory Commission will include those necessary to process any application to construct a repository at Yucca Mountain and to ensure a common understanding of technical information and issues.

C.2.2 STATE AND STATE AGENCIES

C.2.2.1 State of Nevada

If DOE receives authorization to construct, operate and monitor, and eventually close a geologic repository at Yucca Mountain, DOE would need to obtain a range of permits and approvals from the State of Nevada. DOE would need to coordinate application processing activities with the State to complete the permitting processes. DOE could require permits or approvals such as the following:

- An operating permit for control of gaseous, liquid, and particulate emissions associated with construction and operation
- A public water system permit and a water system operating permit for provision of potable water
- A general permit for storm-water discharge
- A National Pollutant Discharge Elimination System permit for point source discharges to waters of the State
- A hazardous materials storage permit to store, dispense, use, or handle hazardous materials
- A permit for a sanitary and sewage collection system
- A solid waste disposal permit
- Other miscellaneous permits and approvals

DOE required similar permits and approvals from the State of Nevada to conduct site characterization activities at Yucca Mountain. DOE and the State coordinated on a range of activities, including an operating permit for surface disturbances and point source emissions, an Underground Injection Control Permit and a Public Water System Permit, a general discharge permit for effluent discharges to the ground surface, a permit for the use of groundwater, a permit from the State Fire Marshal for the storage of flammable materials, and a permit for operation of a septic system. DOE could apply for additional or expanded authority under the existing permits, where needed, if provisions for expansion became applicable. DOE or its contractors could also need to coordinate transportation activities, highway uses, and transportation facility construction and maintenance activities with the Nevada Department of Transportation, including procedures applicable to the construction and operation of roadways.

Interaction

The State of Nevada received a formal briefing on the Draft EIS after its publication. DOE and Nevada Department of Transportation personnel have had informational discussions on Nevada transportation issues.

C.2.3 FEDERAL AND STATE AGENCIES CONSULTED JOINTLY

C.2.3.1 Advisory Council on Historic Preservation and Nevada State Historic Preservation Officer

In the mid- to late-1980s, DOE, the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation discussed the development of a Programmatic Agreement to address DOE responsibilities under Sections 106 and 110 of the National Historic Preservation Act and the Council's implementing regulations. These discussions led to a Programmatic Agreement between DOE and the Advisory Council on Historic Preservation (DIRS 104558-DOE 1988, all) that records stipulations and terms to resolve potential adverse effects of DOE activities on historic properties at Yucca Mountain. The activities covered by the Agreement include site characterization of the Yucca Mountain site under the NWPA and the DOE recommendation to the President on whether or not to develop a repository, informed by a final EIS prepared pursuant to the National Environmental Policy Act and the NWPA.

Although not a formal signatory, the Nevada State Historic Preservation Officer has the right at any time, on request, to participate in monitoring DOE compliance with the Programmatic Agreement. In addition, DOE must provide opportunities for consultations with the Advisory Council on Historic Preservation, the Nevada State Historic Preservation Officer, and Native American tribes as appropriate throughout the process of implementing the Agreement. DOE submits an annual report to the Advisory Council and the Nevada State Historic Preservation Officer describing the activities it conducts each year to implement the stipulations of the Programmatic Agreement. This report includes a description of DOE coordinations and consultations with Federal and State agencies and Native American Tribes on historic and culturally significant properties at Yucca Mountain.

DOE will continue to seek input from the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation, and will interact appropriately to meet the reporting and other stipulations of the Programmatic Agreement.

Interaction

DOE has submitted annual reports to the Nevada State Historic Preservation Officer and the Advisory Council on Historic Preservation and has provided opportunities for consultations with agencies and Native American Tribes as appropriate in accordance with the terms of the Programmatic Agreement.

C.2.4 LOCAL AGENCIES

C.2.4.1 Affected Units of Local Government

As defined by the NWPA, the affected units of local government are local governments (counties) with jurisdiction over the site of a repository. At the discretion of the Secretary of Energy, affected units of local government can also include other local governments that are contiguous to the unit that has jurisdiction. Concerns of the affected units of local government range from socioeconomic impacts to potential consequences of transportation activities. Nye County, Nevada, has jurisdiction over the repository site and is one of the affected units of local government. The Secretary has included Clark, Lincoln, Esmeralda, Mineral, Churchill, Lander, Eureka, and White Pine Counties in Nevada and Inyo County in California as affected units of local government. DOE has also sought input on the Proposed Action from Elko County, Nevada, which is not contiguous to Nye County, but which could be affected by transportation activities associated with the Proposed Action.

DOE has offered local governments the opportunity to submit documents providing perspectives of issues associated with the EIS. At Draft EIS publication, Nye County had prepared such a document.

In addition, other documents related to the Yucca Mountain region have been prepared in the past by several local government units including Clark, Lincoln, and White Pine Counties.

Interaction

DOE has held formal meetings twice a year with the affected units of local government. These meetings have included discussions and status briefings on a range of issues of interest to local governments, including a discussion of the Yucca Mountain program, briefings on the Draft EIS, information exchanges, consultation on permitting processes, and the process for developing responses to comments on the Draft EIS and the Supplement to the Draft EIS. DOE has also held numerous informal meetings with local government representatives. Documents have been received from units of local government.

C.2.5 NATIVE AMERICAN TRIBES

Many tribes have historically used the area being considered for the proposed Yucca Mountain Repository, as well as nearby lands (DIRS 102043-AIWS 1998, p. 2-1). The region around the site holds a range of cultural resources and animal and plant resources. Native American tribes have concerns about the protection of cultural resources and traditions and the spiritual integrity of the land. Tribal concerns extend to the propriety of the Proposed Action, the scope of the EIS, and opportunities to participate in the EIS process, as well as issues of environmental justice and the potential for transportation impacts (DIRS 102043-AIWS 1998, pp. 2-2 to 2-26, and 4-1 to 4-12). Potential rail and legal-weight truck routes would follow existing rail lines and highways, respectively. The legal-weight truck route would pass through the Moapa Indian Reservation and the potential rail line would pass near the Reservation. Potential routes for legal-weight and heavy-haul trucks would follow existing highways, and would pass through the Las Vegas Paiute Indian Reservation.

DOE Order 1230.2 recognizes that Native American tribal governments have a special and unique legal and political relationship with the Government of the United States, as defined by history, treaties, statutes, court decisions, and the U.S. Constitution. DOE recognizes and commits to a government-to-government relationship with Native American tribal governments. DOE recognizes tribal governments as sovereign entities with, in most cases, primary authority and responsibility for Native American territory. DOE recognizes that a trust relationship derives from the historic relationship between the Federal Government and Native American tribes as expressed in certain treaties and Federal law. DOE has and will consult with tribal governments to ensure that tribal rights and concerns are considered before taking actions, making decisions, or implementing programs that could affect tribes. These interactions ensure compliance with provisions of the American Indian Religious Freedom Act (42 U.S.C. 1996 *et seq.*), the Native American Graves Protection and Repatriation Act (25 U.S.C. 3001 *et seq.*), DOE Order 1230.2 (*American Indian Tribal Government Policy*), Executive Order 13007 (*Sacred Sites*), Executive Order 13084 (*Consultation and Coordination with Indian Tribal Governments*), and the National Historic Preservation Act (16 U.S.C. 470f).

Interaction

The Native American Interaction Program was formally begun in 1987. Representatives from the Consolidated Group of Tribes and Organizations have met in large group meetings twice yearly with DOE on a range of cultural and other technical concerns. Additionally, specialized Native American subgroups have been periodically convened to interact with DOE on specific tasks including ethnobotany, review of artifact collections, field archaeological site monitoring, and the EIS process.

The Consolidated Group of Tribes and Organizations consists of the following:

- Southern Paiute
  - Kaibab Paiute Tribe, Arizona
  - Paiute Indian Tribes of Utah
  - Moapa Band of Paiutes, Nevada
  - Las Vegas Paiute Tribe, Nevada
  - Pahrump Paiute Tribe, Nevada
  - Chemehuevi Paiute Tribe, California
  - Colorado River Indian Tribes, Arizona

- Western Shoshone
  - Duckwater Shoshone Tribe, Nevada
  - Ely Shoshone Tribe, Nevada
  - Yomba Shoshone Tribe, Nevada
  - Timbisha Shoshone Tribe, California

- Owens Valley Paiute and Shoshone
  - Benton Paiute Tribe, California
  - Bishop Paiute Tribe, California
  - Big Pine Paiute Tribe, California
  - Lone Pine Paiute Tribe, California
  - Fort Independence Paiute Tribe, California

- Other Official Native American Organizations
  - Las Vegas Indian Center, Nevada

Tribal representatives have prepared and submitted the *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement* (DIRS 102043-AIWS 1998, all). This document discusses site characterization at Yucca Mountain and the Proposed Action in the context of Native American culture, concerns, and views and beliefs concerning the surrounding region. It has been used as a resource in the preparation of the EIS; excerpts are presented in Chapter 4, Section 4.1.13.4, to reflect a Native American point of view. The issues discussed ranged from traditional resources to concerns related to the potential repository.

C.3 Interests of Selected Government Organizations Having Oversight of DOE Activities Related to the Yucca Mountain Repository

C.3.1 COUNCIL ON ENVIRONMENTAL QUALITY

Congress established the Council on Environmental Quality within the Executive Office of the President as part of the National Environmental Policy Act of 1969. In enacting that Act, Congress recognized that nearly all Federal activities affect the environment in some way, and mandated that before Federal agencies take action, they must consider the effects of their actions on the quality of the human environment. It is primarily responsible for coordinating Federal environmental efforts and works closely with agencies and other White House offices in the development of environmental policies and initiatives. One of the Council's primary tasks is overseeing Federal agencies' implementation of the environmental impact assessment process.

Interaction

DOE has provided information and documents, including the Draft EIS and the Supplement to the Draft EIS, to the Council on Environmental Quality. DOE provided a briefing on the Draft EIS and the Supplement to the Draft EIS, including information on schedule, update of the repository design, and opportunities provided for public involvement during the EIS preparation process. Under the NWPA, the Council has a responsibility to provide its comments on the EIS to the President if the Secretary of Energy recommends approval of the Yucca Mountain site.

C.3.2 NUCLEAR WASTE TECHNICAL REVIEW BOARD

The Nuclear Waste Policy Amendments Act of 1987 created the 11-member Nuclear Waste Technical Review Board to evaluate DOE scientific and technical activities related to the management and disposal of the Nation's commercial spent nuclear fuel. The Board's primary responsibility is to evaluate (1) the site characterization phase of the Yucca Mountain Project and the activities associated with determining whether the Yucca Mountain site is suitable for further development as a geologic repository, and (2) the packaging and transportation of spent nuclear fuel and high-level radioactive waste.

The mandate of the Board is to evaluate the scientific and technical work DOE is performing in its commercial nuclear waste disposal program. The Board makes scientific and technical recommendations to DOE to ensure a technically defensible site suitability determination and License Application, and advises DOE on the organization and integration of scientific and technical work pertinent to the Yucca Mountain site.

Interaction

DOE has provided information and work products to the Board, has met with the Board to review aspects of site characterization and the site suitability determination, and has received scientific and technical recommendations from the Board. Many of these interactions were open to the public. DOE provided a briefing on the Supplement to the Draft EIS, including information on schedule, update of the repository design, and opportunities provided for public involvement during the EIS preparation process.

C.4 Requests for Cooperating Agency Status

This EIS addresses a range of potential activities that are of potential concern to other agencies and to Native Americans. Governmental agencies and Native American tribes participated in the EIS process by submitting scoping comments and may submit comments on this Draft EIS. Representatives of Native American tribes have submitted a document that provides their perspective on the Proposed Action. Moreover, DOE has invited local governments in Nevada to submit reference documents providing information on issues of concern.

DOE is the lead agency for this EIS. The lead agency may request any other Federal agency that has jurisdiction by law or special expertise regarding any environmental impact involved in a proposal (or a reasonable alternative) to be a cooperating agency for an EIS (40 CFR 1501.6 and 1508.5). The regulations also allow another Federal agency to request that the lead agency designate it as a cooperating agency. Finally, the regulations allow state or local agencies of similar qualifications or, when the effects are on a reservation, a Native American Tribe, by agreement with the lead agency to become a cooperating agency (40 CFR 1508.5).

If the lead agency designates a cooperating agency, the lead agency's duties toward the cooperating agency include the following:

- Requesting early participation in the National Environmental Policy Act (that is, EIS) process

- Using any environmental analysis or proposal provided by a cooperating agency with legal jurisdiction or special expertise to the greatest extent possible consistent with its responsibilities as a lead agency
- Meeting with a cooperating agency when the cooperating agency requests environmental analyses including portions of the EIS for which the cooperating agency has special expertise
- If the lead agency requests, making staff support available
- Using its own funds, except the lead agency is to fund major activities or analyses it requests to the extent available

Several agencies, tribes, or tribal organizations have either requested cooperating agency status for this EIS, made comparable proposals for participation, or stated positions in regard to the extent of their participation. Table C-2 summarizes agency requests, proposals, and position statements together with the DOE responses, if appropriate. DOE did not designate any cooperating agencies for this EIS process.

Table C-2. History of requests for cooperating status and similar proposals (page 1 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
U.S. Department of the Navy	Request for cooperating agency status (DIRS 104637-Guida 1995, all)	May 23, 1995	DOE can draw on existing information from Navy participation in other EISs. DOE will conduct close consultations to ensure accuracy of information used. DOE declines cooperating agency status (DIRS 104625-Dixon 1995, all).	July 10, 1995
U.S. Department of the Interior, National Park Service	Request for cooperating agency status (DIRS 104643-Martin 1995, all)	September 21, 1995	DOE prefers to address NPS comments or issues related to the Death Valley National Park through close consultations between the two agencies. DOE declines cooperating agency status (DIRS 104627-Dixon 1995, all).	November 11, 1995
Nye County	Request for cooperating agency status (DIRS 104645-McRae 1995, all) (DIRS 104614-Bradshaw 1995, all) (DIRS 104630-YMP 1997, all) (DIRS 104615-Bradshaw 1998, all)	August 15, 1995 October 4, 1995 December 5, 1995 July 30, 1998	DOE expresses appreciation for the County's interest and desire to participate, commits to active consultations with Nye County and other entities on selected issues during EIS development, outlines general elements of consultation and coordination contemplated by DOE. DOE declines cooperating agency status (DIRS 104604-Barnes 1995, all) (DIRS 104605-Barnes 1995, all) (DIRS 104608-Barrett 1998, all).	November 21, 1995 December 1, 1995 September 24, 1998
Churchill County	Request for cooperating agency status (DIRS 104653-Regan 1995, all)	May 30, 1995	DOE does not foresee the need to establish formal MOUs to govern Churchill County's or other parties' participation in the NEPA process for the Repository EIS. CEQ and DOE regulations provide sufficient guidance for participation of all affected units of local government and members of the public. DOE describes steps being taken to ensure all interested and potentially affected organizations and individuals have early and equal opportunity to participate in EIS development. DOE declines cooperating agency status (DIRS 104606-Barnes 1995, all).	July 21, 1995

Table C-2. History of requests for cooperating status and similar proposals (page 2 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
Lincoln County	Proposal for a cooperative agreement with DOE in assessing the continued development of rail and highway route options to the Yucca Mountain site (DIRS 104656-Wright 1996, all).	April 22, 1996	DOE expresses appreciation for the County's desire to participate in DOE transportation planning activities, but indicates that, because much of the planning will be done to support the EIS, a cooperative agreement would be unnecessary. DOE identifies active consultation and coordination as an objective of the EIS process (DIRS 104610-Benson 1996, all).	August 2, 1996
Nuclear Regulatory Commission	NRC does not intend to participate as a cooperating agency (DIRS 104640-Holonich 1995, all)	March 1, 1995	DOE sent no response to this letter.	NA
Nuclear Regulatory Commission	NRC sent a letter (July 7, 1997) to the Navy. The NRC letter responded to a Navy transmission to the NRC of information on naval spent nuclear fuel. The information had been prepared for EIS use. In its letter, the NRC indicated that it would evaluate the information as part of prelicensing consultations with DOE on waste form issues but that, because NRC is required to review and adopt any EIS submitted as part of a DOE License Application, including information on naval SNF, NRC staff does not intend to formally review and comment on the Navy data. NRC sent DOE a copy of its response to the Navy (DIRS 104654-Stablein 1997, all).	August 22, 1996	NA	NA

Table C-2. History of requests or cooperating status and similar proposals (page 3 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
U.S. Department of Air Force	Letter from USAF to the State of Nevada, stating that DOE has no obligation to consult with USAF regarding the transportation options DOE elects to evaluate as a result of NEPA public scoping comments, including the Caliente-Chalk Mountain heavy-haul route through Nellis Air Force Range. USAF acknowledged its close interaction with YMP and its intent to "continue this close relationship" (DIRS 104632-Esmond 1997, all).	September 4, 1997	NA	NA
Council of Energy Resources Tribes	Concept paper for Native American participation in the production of the YMP EIS (DIRS 104622-Burnell 1996, all).	June 19, 1996	DOE expressed thanks for the concept paper, described the status of the EIS (deferred during Fiscal Year 1996), committed to consideration of comments expressed in the concept paper along with all other comments received during the public scoping process. DOE stated that it would prepare a scoping comment summary and make the summary publicly available, indicated its active consideration of various approaches to consultations with other agencies and Native American tribes, including possible preparation of an EIS-referenceable document (DIRS 104629-Dixon 1996, all).	July 26, 1995
Advisory Council on Historic Preservation	Expressed thanks for DOE invitation to participate in the EIS process. Indicated desire to assist with development of the EIS and availability to assist DOE in complying with environmental review requirements; expressed intent to provide comments on the draft EIS (DIRS 104652-Nissley 1995, all).	October 12, 1995	DOE did not prepare a response to this formal scoping comment.	NA

Table C-2. History of requests for cooperating status and similar proposals (page 4 of 4).

Agency	Request/statement/offer	Date	DOE response	Date
Timbisha Shoshone Tribe of Death Valley, California	Letter to President Clinton expressing opposition to YMP; enclosed a Tribal Resolution condemning the siting of YMP; requested active involvement/consultation at a government-to-government level (DIRS 104613-Boland 1996, all).	August 14, 1996	DOE acknowledged expressed concerns and Tribal Resolution; identified ongoing Native American Interaction Program as vehicle to promote consultations and protection of cultural resources in YMP area; stated that comments from tribal governments were actively solicited during scoping period and Timbisha Shoshone will be afforded opportunity to comment on Draft EIS following its publication (DIRS 104607-Barnes 1996, all).	November 12, 1996
National Congress of American Indians	Letter expressed thanks to DOE (Secretary O'Leary) for invitation to meeting of public and private officials to exchange views on DOE management of SNF and radioactive waste, described NCAI as an organization, described Federal Government's fiduciary duty to tribes as sovereign nations, discussed lack of "affected status" for tribes under the NWPA, state Secretary O'Leary's three commitments to Federally recognized tribes in the Yucca Mountain area during the last year, including inclusion in future Yucca Mountain consultations, requested that DOE and Congress mandate a participatory role for tribal governments as part of any proposals to change the NWPA (DIRS 104633-Gaiashkibos 1995, all).	March 1, 1995	NA	NA

a. Abbreviations: CEQ = Council on Environmental Quality; MOU = Memorandum of Understanding; NA = not applicable; CAI = National Congress of American Indians; NEPA = National Environmental Policy Act; NPS = National Park Service; NRC = U.S. Nuclear Regulatory Commission; NWPA = Nuclear Waste Policy Act; SNF = spent nuclear fuel; USAF = U.S. Air Force; YMP = Yucca Mountain Project.

REFERENCES

102043	AIWS 1998	AIWS (American Indian Writers Subgroup) 1998. *American Indian Perspectives on the Yucca Mountain Site Characterization Project and the Repository Environmental Impact Statement*. Las Vegas, Nevada: Consolidated Group of Tribes and Organizations. ACC: MOL.19980420.0041.
104604	Barnes 1995	Barnes, W.A. 1995. "Nye County's Request for Cooperating Agency Designation." Letter from W.A. Barnes (DOE/YMSCO) to The Honorable C. McRae, November 21, 1995, MFR:AMESH:WRD-4730, with enclosure. ACC: MOL.19960424.0182.
104605	Barnes 1995	Barnes, W.E. 1995. Response to the Proposed Memorandum of Understanding in Support of Nye County's Previous Request for Cooperating Agency Designation. Letter from W.E. Barnes (DOE/YMSCO) to L. Bradshaw (Nye County Department of Natural Resources & Federal Facilities), December 1, 1995, MFR:AMESH:WRD-501, with enclosure. ACC: MOL.19960425.0310.
104606	Barnes 1995	Barnes, W.E. 1995. "Proposed Memorandum of Understanding (MOU) Regarding the U.S. Department of Energy's (DOE) Preparation of an Environmental Impact Statement (EIS) for a Potential Repository at Yucca Mountain, Nevada." Letter from W.E. Barnes (DOE/YMSCO) to J. Regan (Chairman Churchill County Commissioners), July 21, 1995, AMESH:WRD-3636. ACC: MOL.19951220.0136.
104607	Barnes 1996	Barnes, W.E. 1996. Response to R.F. Boland's Letter to President Clinton Dated August 14, 1996, Concerning the Yucca Mountain Site Characterization Project (YMP). Letter from W.E. Barnes (DOE/YMSCO) to R.F. Boland (Chief Spokesperson, Timbisha Shoshone, Death Valley Land Restoration Project), November 12, 1996, MFR:AMESH:JPC-0276. ACC: MOL.19970210.0099.
104608	Barrett 1998	Barrett, L.H. 1998. Response to L.W. Bradshaw Letter of July 30, 1998, Requesting Designation of Nye County, Nevada as a Cooperating Agency in the Preparation of the Department of Energy's (DOE) Yucca Mountain Repository Environmental Impact Strategies. Letter from A.B. Benson (DOE/YMSCO) to E.E. Wright (Lincoln County Commissioner), August 02, 1996, MFR:OPA:ABB-2312. ACC: MOL.19990610.0300.
104610	Benson 1996	Benson, A.B. 1996. Response to Letter Dated April 22, 1996 from The Honorable E.E. Wright, Regarding the Department's Preliminary Transportation Strategies. Letter from A.B. Benson (DOE/YMSCO) to E.E. Wright (Lincoln County Commissioner), August 2, 1996. MFR:OPA:ABB-2312. ACC: MOL.19961115.0045.

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104652	Nissley 1995	Nissley, C. 1995. Advisory Council on Historic Preservation Participation in the Preparation of an Environmental Impact Statement (EIS) for a Geologic Repository at Yucca Mountain. Letter from C. Nissley (Advisory Council on Historic Preservation) to W. Dixon (DOE/YMSCO), October 12, 1995. ACC: MOL.19990319.0206.
104653	Regan 1995	Regan, J. 1995. Revised Version of the Memorandum of Understanding (MOU) Between Churchill County and the U.S. Department of Energy (DOE) Regarding Responsibilities and Roles. Letter from J. Regan (Churchill County Commissioners) to M. Powell (DOE), May 30, 1995, with enclosure. ACC: MOL.19990610.0299.

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Appendix D

Distribution List

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APPENDIX D. DISTRIBUTION LIST

The U.S. Department of Energy (DOE) is providing copies of this Final EIS to Federal, state, and local elected and appointed officials and agencies of government; Native American groups; national, state, and local environmental and public interest groups; and other organizations and individuals listed below. In addition, DOE is sending copies of the Final EIS to all persons who commented on the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* and the Supplement to the Draft EIS; these individuals are listed in Table CR-2 in the Comment-Response Document (Volume III of this Final EIS). DOE will provide copies to other interested organizations or individuals on request.

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Appendix E

Environmental Considerations for Alternative Design Concepts and Design Features for the Proposed Monitored Geologic Repository at Yucca Mountain, Nevada

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E.1 Introduction

E.1.1 PURPOSE

The purpose of this appendix is to give the reader a perspective on the development of the conceptual design used for environmental impact analysis of the proposed Yucca Mountain Repository in this Final Environmental Impact Statement (EIS). The basic design concept of packaging spent nuclear fuel and high-level radioactive waste in corrosion-resistant, long-life containers for emplacement in drifts drilled into the unsaturated rock structure of Yucca Mountain has not changed from the design evaluated in the Draft EIS. The flexible design evaluated in this Final EIS does, however, include a number of features and alternatives that were not part of the Draft EIS design. The U.S. Department of Energy, (DOE or the Department) added these features and alternatives to the design primarily to increase operational flexibility, enhance long-term performance, and reduce long-term uncertainty. DOE presented the flexible design and evaluated its environmental impacts in the Supplement to the Draft EIS.

E.1.2 BACKGROUND

E.1.2.1 General Background

The preliminary conceptual design used for environmental analysis in the Draft EIS was described in the *Viability Assessment of a Repository at Yucca Mountain* (DIRS 101779-DOE 1998, all), and was referred to as the Viability Assessment reference design. The Viability Assessment concluded that "uncertainties remain about key natural processes, the preliminary conceptual design and how the site and the design would interact" (DIRS 101779-DOE 1998, Overview, p. 2). Recognizing that the design would continue to develop, the Viability Assessment noted that "DOE is evaluating several design options and alternatives that could reduce existing uncertainty and improve the performance of the repository system" (DIRS 101779-DOE 1998, Overview, p. 30). DOE evaluated the design options in the License Application Design Selection project.

E.1.2.2 Background on the License Application Design Selection Project

Phase I of the License Application Design Selection project involved identifying and analyzing a set of design features and design alternatives that had potential value as elements in the repository design. Phase I was underway as the Draft EIS was being prepared. Accordingly, Appendix E of the Draft EIS contained a list of the design features and alternatives that had been developed to that point in time along with some very preliminary discussion of potential benefits and potential environmental impacts. Phase II of the License Application Design Selection project involved developing a set of enhanced design alternatives from combinations of the design alternatives and features prepared in Phase I. The following definitions of design features, design alternatives, and enhanced design alternatives, provide insight into how the process worked.

- Design alternative—Each design alternative represents a fundamentally different conceptual design for the repository and could stand alone as the License Application repository design concept. Design alternatives are distinguished from design features by their complexity and the number of attributes involved. Design alternatives, while not mutually exclusive, represent diverse and independent methods of accomplishing the repository mission—safe disposal of spent nuclear fuel and high-level radioactive waste. One example of a design alternative is a repository designed to use continuous natural ventilation to remove heat and moisture from the area of the waste packages after the repository has been closed.

- Design feature—A design feature is a particular element or attribute of the repository that could be added to a design alternative to enhance its performance. An individual design feature can represent a discrete concept, such as use of shielded waste packages, or a continuous range of values of some aspect of repository design, such as spacing of the waste emplacement drifts. Design features can be added to any design alternative singly or in combination, although the compatibility of different design alternatives and design features varies.

- Enhanced design alternative—Enhanced design alternatives are combinations of one or more design alternatives and design features that fit logical principles derived from the objectives for repository design. Enhanced design alternatives selected for evaluation are those combinations that include mutually compatible attributes and expected postclosure performance characteristics that exceed those of the basic design alternatives. Other characteristics considered in developing enhanced design alternatives include the compatibility of the design alternatives and design features; the developmental, operational, and maintenance simplicity of the resulting combination; and the ability of the set of enhanced design alternatives to address the entire set of design alternatives and design features.

The final *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all) recommended, and DOE subsequently chose, a particular combination of design alternatives and features called Enhanced Design Alternative II to carry forward in the design evolution. However, DOE did specify that backfill should be only a possible option in Enhanced Design Alternative II. Accordingly, DOE adopted Enhanced Design Alternative II without backfill as the design for continued development.

E.1.2.3 Background on the Science and Engineering Report

The current repository conceptual design, which is based on Enhanced Design Alternative II without backfill, is discussed in the *Yucca Mountain Science and Engineering Report: Technical Information Supporting Site Recommendation Consideration* (DIRS 153849-DOE 2001). This report was the basis for the Supplement to the Draft EIS and remains the basis for this Final EIS.

The flexible design described in the Science and Engineering Report and in the Supplement to the Draft EIS uses more extensive thermal management techniques to limit the heat released by the waste than the design evaluated in the Draft EIS. In addition to the design enhancements that would result directly from the proposed features and design alternatives discussed below, this design would be the most flexible in terms of accommodating other higher- or lower-temperature operating conditions.

The following sections identify and describe the design features and alternatives that DOE has considered in the design evolution of the repository. Some of the features and alternatives discussed in the following paragraphs have been incorporated in the current design. Most, while no longer being actively considered, have not been eliminated entirely. DOE expects the design to continue to evolve through the licensing process, so additional limited development and enhancement could occur as the design matures. The features and alternatives described below provide a framework for the design evolution that has occurred to date, and any future design evolution, along with a qualitative evaluation of environmental impacts.

E.1.3 SUMMARY OF DESIGN ALTERNATIVES AND FEATURES

The design alternatives and features considered in the development of the flexible design analyzed in the Final EIS are listed in Tables E-1 and E-2. The design alternatives and design features listed in Tables E-1 and E-2, respectively, are listed in the same order and with the same title as in the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). Design features 21 and 22, Dry Handling and Site Access Road, respectively, were not included in the License Application Design Selection study and neither was included in Appendix E of the Draft EIS, but they are currently being considered for future potential repository evolution. The titles include parenthetical comments in italics that are intended to help the reader identify the specific attributes of the alternatives and features.

Table E-1. Design alternatives.

Alternative	Title	Text	Purpose	Status
1	Tailored Waste Package Spatial Distribution *(to improve heat distribution in the drifts)*	E.2.1.1	HM	CI
2	Low Thermal Load *(about 25 MTHM/acre)*	E.2.1.2	HM	PA
3	Continuous Postclosure Ventilation *(natural ventilation)*	E.2.1.3	HM	CI
4	Enhanced Access *(shielding to permit personnel access to the emplacement drifts)*	E.2.1.4	CO	CI
5	Modified Waste Emplacement Mode *(use natural shielding such as vertical emplacement of waste packages to permit personnel access)*	E.2.1.5	CO	CI
6	Viability Assessment Design *(85 MTHM/acre)*	E.2.1.6	HM	CI
7	Viability Assessment Design with Options *(ceramic coating, backfill and drip shield[a])*	E.2.1.7	HM	CI
8	Modular Design (Phased Construction) *(phased construction of facilities to provide funding flexibility)*	E.2.1.8	CO	AE

a. Drip shields are listed as a design feature in Table E-2.

The tables include a column titled text, which lists the section of this appendix that contains additional description of the alternative or feature.

The column titled Purpose indicates the purpose or nature of the alternative or feature with respect to repository performance. The codes for the entries are:

Purpose of design alternative or feature:

RT— Enhance the barrier to prevent release and transport of fission products

HM— Control heat and moisture in the repository to reduce the potential for corrosion of the waste packages

CO— Support cost and operation considerations

The column titled Status indicates the current disposition of each alternative or feature as follows:

Status:

PA— Included in the impact analysis of the flexible design for the Proposed Action

AE— Additional evaluation to be conducted

CI— Currently inactive *(but not eliminated from further consideration)*

NF— Not considered feasible in conjunction with the flexible design

Table E-2. Design features.

Feature	Title	Text	Purpose	Status
1	Ceramic Coatings *(on the waste package)*	E.2.2.1	RT	CI
2	Backfill *(in the emplacement drifts)*	E.2.2.2	RT	CI
3	Drip Shield *(over the waste package)*	E.2.2.3	RT	PA
4	Preemplacement Aging and Blending of Waste *(commercial spent nuclear fuel only)*	E.2.2.4	HM	PA
5	Continuous Preclosure Ventilation *(both forced ventilation and natural ventilation of emplacement drifts)*	E.2.2.5	HM	PA/AE[a]
6	Rod Consolidation *(commercial spent nuclear fuel only)*	E.2.2.6	HM	CI
7	Timing of Repository Closure and Maintenance of Underground Facilities and Ground Support *(consideration of the repository being open for 300 years or more)*	E.2.2.7	HM	PA
8	Drift Diameter *(of the emplacement drifts)*	E.2.2.8	HM	CI
9	Waste Package Spacing and Drift Spacing	E.2.2.9	HM	PA
10	Waste Package Self Shielding	E.2.2.10	CO	CI/NF
11	Waste Package Corrosion Resistant Materials	E.2.2.11	RT	PA
12	Richards Barrier *(to divert moisture away from the waste package by capillary action)*	E.2.2.12	HM	CI
13	Diffusive Barrier/Getter Under the Waste Package	E.2.2.13	RT	CI
14	Canistered Assemblies *(for commercial spent nuclear fuel only)*	E.2.2.14	RT	CI
15	Additives and Fillers *(inside the waste package)*	E.2.2.15	RT	CI
16	Ground Support Options *(to prevent rockfall in the emplacement drifts*	E.2.2.16	RT	PA
17	Near-Field Rock Treatment during Construction *(to limit seepage of water into the drifts)*	E.2.2.17	HM	CI
18	Surface Modifications *(to limit infiltration of water into the mountain)*	E.2.2.18	HM	CI
19	Repository Horizon Elevation	E.2.2.19	CO	CI
20	Higher Thermal Loading	E.2.2.20	HM	CI
21	Dry Handling *(of commercial spent nuclear fuel in the Waste Handling Building)*	E.2.2.21	CO	AE
22	Site Access Road *(from U.S. 95 to the North Portal on the west side of Fortymile Wash)*	E.2.2.22	CO	AE

a. Natural ventilation for the preclosure period is undergoing additional evaluation.

The tables indicate that eight alternatives and 22 features have been identified for consideration in finalizing the repository design. One alternative and seven features have been integrated into the flexible design analyzed for the Proposed Action in the Supplement to the Draft EIS and in the Final EIS. One additional alternative and three additional features will be evaluated further as the design matures. The six alternatives and 13 features that are listed as currently inactive (CI) have not been eliminated from consideration, but they were not considered in the environmental impact analysis for the Final EIS. Self shielding of waste packages, feature 10, is not considered feasible in conjunction with the waste package design used for the Final EIS.

The following sections provide brief descriptions of each of the alternatives and features. For the alternatives and features that are subject to additional evaluation (status AE), preliminary information on potential benefits and environmental impacts is provided. The benefits and impacts for the alternatives and features included in the flexible design (status PA) are discussed in the body of the Final EIS; for those with an inactive status (CI), the potential benefits and impacts have not been discussed.

E.2 Design Alternatives and Features

The summary descriptions of the design alternatives and features provided in the following sections are composite descriptions using data and text from both Appendix E of the Draft EIS and from the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). The *License Application Design Selection Report* provides references for additional data and information on many of the design alternatives and features.

E.2.1 DESIGN ALTERNATIVES

As mentioned above, the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all) and this Appendix discusses eight design alternatives. Six of these alternatives are currently inactive and DOE did not consider them in the impact analysis for this EIS. One of the draft alternatives, low thermal load, has been incorporated in the flexible design evaluated in the Proposed Action. The remaining alternative, Modular Design, would be evaluated further as the final repository design matures. The following sections provide a brief description of the design alternative from the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). For the modular design, DOE has also provided a qualitative assessment of the potential benefits and environmental considerations should DOE adopt this alternative at a later time.

E.2.1.1 Design Alternative 1, Tailored Waste Package Spatial Distribution

This design alternative addresses the position and placement of specific types of waste in the repository block emplacement drifts to determine if the postclosure isolation performance of the repository could be improved. The Draft EIS design emplaced the waste packages in the order received, with the only restrictions being the total amount of heat per acre and adjacent package heat considerations. This design alternative evaluation identifies combinations of site characteristics and waste forms and packages that would provide improved waste isolation performance and that practicable engineering could support. An example application would be grouping waste package types into categories of hot, medium, and cold to even the temperature differences across the repository or in a drift.

E.2.1.2 Design Alternative 2, Low Thermal Load

The low thermal load design alternative formed the basis for the flexible design evaluated in the Supplement to the Draft EIS and the Final EIS. The basic premise of this alternative is that a lower thermal load would limit the temperature of the drift wall and host rock and, thereby, would reduce uncertainties in predicting thermal, chemical, mechanical, and hydrological effects. As demonstrated in the Supplement to the Draft EIS and this Final EIS, the lower-temperature repository operating mode could be achieved by varying certain operational parameters such as waste package spacing, ventilation rate and duration, and waste package loading.

E.2.1.3 Design Alternative 3, Continuous Postclosure Ventilation

The postclosure ventilation design alternative identifies a series of conceptual designs aimed at utilizing ventilation in the emplacement drifts during the postclosure period. The expected benefit provided by postclosure ventilation would be improved waste package performance. Improved performance could be achieved by limiting the amount of water or humidity contacting the waste packages, which would reduce corrosion. A ventilated repository could reduce the emplacement drift air temperature, as well as the relative humidity, rock saturation, and rock temperature.

E.2.1.4 Design Alternative 4, Enhanced Access

This design alternative considers the approach of providing sufficient radiation shielding for the waste packages to allow personnel access during handling and inspection operations. This, in turn, would simplify component design and operations. Access to the emplacement drifts would be provided so personnel could execute performance confirmation activities and maintenance.

E.2.1.5 Design Alternative 5, Modified Waste Emplacement Mode

In this design alternative, unshielded waste packages would be placed in a configuration where the repository's natural or engineered barriers would provide the personnel shielding. This alternative is similar to the enhanced access design in that personnel could access areas near the waste packages, but in this design alternative the waste packages would not have to be shielded. Various configurations for accomplishing the shielding using the natural and engineered barriers would be considered. Examples include placing waste packages in boreholes drilled into the floor or wall of emplacement drifts, in alcoves off the emplacement drifts, in trenches at the bottom of the emplacement drifts, or in short cross-drifts excavated between pairs of excavated drifts. In each case, some type of cover plug would be used to shield radiation in the emplacement drifts.

E.2.1.6 Design Alternative 6, Viability Assessment Reference Design

The Viability Assessment reference design is equivalent to the high thermal load alternative (85 MTHM per acre) evaluated in the Draft EIS. The complete description of this design is presented in Chapter 2 of the Draft EIS.

E.2.1.7 Design Alternative 7, Viability Assessment Reference Design with Options

The Viability Assessment reference design with options was considered as a design alternative in the License Application Design Selection process. Options considered include ceramic coatings, backfill, and drip shields (see Sections E.2.2.1, E.2.2.2, and E.2.2.3, respectively).

E.2.1.8 Design Alternative 8, Modular Design (Phased Construction)

This design alternative considers the effects of separating the Waste Handling Building, the Carrier Preparation Building, and the subsurface repository into multiple modules, structures, or phases to be constructed over time. Direct support facilities such as the Waste Treatment Building, the balance of the plant support facilities, and any additional facilities required for the support of early receipt or storage could also be phased.

Six alternative design concepts were considered to determine the impact on waste throughput quantities. These concepts were reviewed to determine how they would perform in relation to funding constraints, waste receipt and storage, and emplacement rates. Subsurface construction and phasing to meet estimated emplacement rates were reviewed to determine the most effective method.

DOE would evaluate this design alternative further as the repository design matures, and as funding forecasts were identified.

E.2.1.8.1 *Potential Benefits*

Modular design is an alternative that could reduce annual expenditures during construction if annual funding is constrained below that required for the Proposed Action.

E.2.1.8.2 *Potential Environmental Considerations*

Modular design is an alternative that would probably increase the total facility cost and the environmental impacts by about 20 to 30 percent. Constructing multiple facilities to handle the same capacity would increase nearly all impacts because many systems (for example, ventilation systems) would need to be partially duplicated and total building floor space would increase. In addition, construction of the later facilities would be carried out in parallel with nuclear operations on the site, which would result in the need for careful control and monitoring of construction activities. All of the impacts would likely be extended over a longer period. Annual impacts could remain nearly the same but total impacts would be likely to increase.

E.2.2 DESIGN FEATURES

This section describes the 22 design features, 20 of which DOE evaluated as part of the *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all). Seven of these features have been incorporated (some only partially) in the flexible design evaluated in the Proposed Action. Based on the current design, 13 of the features are either inactive or not feasible. For the features that are being evaluated for incorporation as the design matures, DOE has provided a qualitative assessment of their potential benefits and potential environmental considerations.

E.2.2.1 Ceramic Coatings

A thin coating [1.5 millimeters (0.06 inch) or more] of a ceramic oxide on the outer surface of the waste package could increase the life of the waste package by slowing the rate at which the waste package corroded. Several thermal processes produce high-density coatings on metals, and the range of materials that can be applied is extensive. The coating materials that could be considered include magnesium aluminate spinel, aluminum oxide, titanium oxide, and zirconia-yttria. This design feature is no longer under active consideration, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.2 Backfill

At repository closure, loose, dry, granular material such as sand or gravel would be placed over the waste packages in a continuous, heaped pile. Other materials for backfill, such as crushed rock and depleted uranium, could be considered. The waste packages would generate heat after emplacement, and this heat would tend to drive water away from the emplacement location. Backfill would act as insulation for the waste packages, keeping them hotter. The emplacement areas would stay hotter longer, which could retard the onset of waste package corrosion by delaying the onset of water contacting the packages. The waste packages would gradually cool off and become potentially vulnerable to corrosion caused by water and corrosive minerals dissolved in the water. In addition to providing thermal insulation, the backfill (without proposed drip shields) would provide some protection to the waste package from rockfall. This design feature is no longer under active consideration.

As discussed in Chapter 2, Section 2.1.2.4, backfill would be used for the Proposed Action for main drifts, access ramps, and ventilation shafts. The backfill for these drifts and shafts would be installed during closure. Backfill is not currently planned for use in the emplacement drifts.

E.2.2.3 Drip Shields

Drip shields over the waste packages would provide a partial barrier by diverting falling rocks and infiltrating water away from waste packages in an emplacement drift. Corrosion-resistant metals (titanium or Alloy-22), metals with ceramic coatings, and monolithic ceramics have been considered as drip shield materials. One option would be to place drip shields under backfill; another would be to place the drip shields over the backfill. Drip shields could be implemented with or without backfill.

The drip shield, if used over the backfill, would be formed to the approximate backfill surface profile and placed atop the backfill (or Richards Barrier). With this option, the drip shield would be placed in conjunction with the placement of backfill at repository closure.

For the Final EIS, DOE has incorporated the use of drip shields without backfill as part of the Proposed Action.

E.2.2.4 Aging and Blending of Waste

Pre-emplacement aging and blending of commercial spent nuclear fuel would provide mechanisms for managing the thermal output of a waste package and the total thermal energy that the repository would have to accommodate.

Aging the waste before emplacement would result in less variable (over time) thermal output of the waste packages and lower waste package temperatures.

Blending would allow a more uniform heat output from the waste packages. Blending would be accomplished by selecting waste forms for insertion in waste packages based on their heat output to minimize the variability in the thermal energy of each waste package and to lower peak waste package heat output.

Aging and blending would not be necessary for DOE spent nuclear fuel and high-level radioactive waste.

Both aging and blending would require additional facilities at the repository. A 5,000-MTHM-equivalent storage pool would be required to support blending and a large surface storage pad along with large storage casks would be required to support aging. The capability to age and blend commercial spent nuclear fuel has been incorporated as part of the Proposed Action in this Final EIS.

E.2.2.5 Continuous Preclosure Ventilation

During preclosure, a ventilation system would deliver a specified volume of air to the emplacements drifts containing waste packages. This continuous ventilation would reduce air and drift temperatures, and would carry away heat and moisture that could otherwise increase corrosion. The host rock would remain drier and cooler during preclosure compared to a repository (such as the Draft EIS design) where there was little ventilation.

The ventilation could be provided using forced flow driven by electric-motor-powered fans or by natural ventilation. Forced-flow ventilation is included in the Proposed Action and is discussed in Volume I of this Final EIS. The heat generated by the spent nuclear fuel and high-level radioactive waste could develop and maintain a temperature difference to drive passive ventilation of the emplacement drifts throughout the maximum time the repository would remain open. This is called *natural ventilation*. The heat from the waste could be used to draw cooler, drier external air through the intake shafts, across the emplacement drifts, and out the exhaust shafts (located at an elevation above the intakes), much the way heat from a fireplace draws air from a room and exhausts it through a chimney. Passive ventilation is used to regulate air temperature in buildings and has similar uses in large subsurface structures such as mines. Findings in numerous caves that are analogous to a deep geologic repository (DIRS 153849-DOE 2001, Section 2.1.5.4) support the idea that the environment of a naturally ventilated underground system could, under certain conditions, preserve materials for several thousand years and could greatly reduce waste package degradation.

Natural ventilation during preclosure is the subject of additional evaluation for potential future repository evolution. The environmental impacts of natural ventilation were evaluated in one of the lower-temperature operating modes for this Final EIS. Methods for implementing this feature would require further evaluation, as discussed below.

E.2.2.5.1 *Potential Benefits*

The primary benefit of natural ventilation for the removal of heat and moisture would be the reduction in energy use and reduction in maintenance compared to systems using forced-flow ventilation driven by electric fans, potentially required to operate for hundreds of years. Benefits of forced-flow ventilation are addressed in Chapter 2 as part of the Proposed Action.

E.2.2.5.2 *Potential Environmental Considerations*

Additional excavation could be required to optimize the repository configuration for natural ventilation. The actual number of emplacement drifts might not change, but the layout of drifts could vary slightly to accommodate additional or reoriented ventilation shafts. The sizes of the shafts might have to be increased. A backup forced ventilation system could be needed to provide “blast cooling” to support maintenance. Environmental impacts of forced-flow ventilation are addressed in Chapter 4 as part of the Proposed Action.

E.2.2.6 Rod Consolidation

Both pressurized-water reactor and boiling-water reactor fuel assemblies have fuel rods arranged in regular square arrays with rod-to-rod separations maintained by fuel assembly hardware. Rod consolidation would involve taking the fuel rods out of the arrays and bringing them into direct contact with one another. This would reduce the volume required by fuel assemblies and would allow increases in the capacity of waste packages or reduction in waste package size. The fuel assemblies would be consolidated by removing the fuel rods from the assembly and placing them in a canister. Each canister could contain fuel rods from one or more fuel assemblies. The canisters would then be loaded into the waste package. Nonfuel components (control rods, channels, etc.) would be separated from the fuel assemblies for disposal by other methods. The remainder of the assembly hardware would be disposed of separately. The consolidation process could occur in a pool or shielded dry environment. This design feature is no longer under active consideration because the concentration of thermal energy inherent in rod consolidation is not consistent with the flexible design operating modes.

E.2.2.7 Timing of Repository Closure and Maintenance of Underground Facilities and Ground Support

The timing of the repository closure design feature addresses the changes in performance criteria that result from consideration of a monitoring phase as long as 300 years, rather than the 100-year period from initiation of waste emplacement used in the Draft EIS design. Included in the design feature were requirements to facilitate keeping the repository open for an additional 200 years, the related cost implications, and a risk assessment. The maintenance of underground facilities and ground support design features was included in this design feature because the two features would be interrelated. Underground facilities and ground support would affect the level of maintenance in the emplacement drifts needed to accommodate an extended long-term repository service life. One benefit of a maintenance program would be that it could reduce the risk of rockfall in the emplacement drifts. This feature is included as part of the Proposed Action lower-temperature operating mode.

E.2.2.8 Drift Diameter

The diameter of the emplacement drift is influenced by a number of primary design features. Heat management strategies, emplacement mode, and emplacement equipment are major influencing factors. The size of the emplacement drift could directly affect design considerations such as opening stability (rockfall potential), the extent of the mechanically induced disturbed zone, and the amount and location of moisture seepage into the drifts. These design considerations could affect repository performance. The drift diameter for the Draft EIS design was 5.5 meters (18 feet). The 5.5-meter drift diameter was maintained in the Supplement to the Draft EIS and in this Final EIS. DOE is not actively considering a change in drift diameter because other drift diameters do not enhance the performance or operation of the flexible design operating modes. The drift diameter for the flexible design was standardized at 5.5 meters (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.4).

E.2.2.9 Drift Spacing and Waste Package Spacing

Drift spacing is the distance between two consecutive drifts. Waste package spacing is the distance between the ends of two consecutive waste packages. For a given drift spacing, emplacement of waste packages can be arranged by using point load (waste package spacing based on individual package characteristics, such as mass content or equivalent heat output), or line load [waste packages emplaced nearly end to end with a 0.1-meter (0.3-foot) gap and with no consideration of individual waste package characteristics].

The point load approach to thermal analysis was used for the scenarios evaluated in the impact analysis for the Draft EIS design. Waste package spacing was based on the mass content of waste packages, to achieve an overall area mass loading from 25 MTHM per acre to 85 MTHM per acre for commercial spent nuclear fuel. The higher-temperature repository operating mode evaluated in the Final EIS is a line load configuration with 0.1-meter (0.3-foot) waste package spacing and 81-meter (270-foot) drift spacing. The lower-temperature repository operating mode evaluated in the Final EIS uses the 81-meter drift spacing but considers spacing ranging from about 2.1 to 6.4 meters (6.9 to 21 feet).

E.2.2.10 Waste Package Self-Shielding

In the repository designs evaluated to date, handling of waste packages in the emplacement drifts would be performed remotely, and human access to the emplacement drifts would be precluded if waste packages were present. Waste package self-shielding would reduce the radiation in the drifts to levels such that personnel access would be possible. This would allow direct access to the performance confirmation instrumentation, and for maintenance and repair in the drifts.

Self-shielding would be accomplished by adding a shielding material around the waste packages. Candidate materials include A516 carbon steel, concrete with depleted uranium (Ducrete®), magnetite concrete, and a composite material of boron-polyethylene and carbon steel.

The amount of shielding would depend on the target radiation dose level in the drift environment. Because the amount of shielding would substantially increase the weight and size of the loaded waste packages, it is not considered feasible with the current waste package design. This design feature is no longer under active consideration.

E.2.2.11 Waste Package Corrosion-Resistant Materials

The Draft EIS design for the waste package used two concentric barrier layers: an outer A516 carbon steel corrosion-allowance material that would provide structural strength during handling, and an inner nickel-based Alloy-22 corrosion-resistant material. These two barriers would be expected to provide substantially complete containment of the waste for the lifetime goals established in the Viability Assessment; however, a waste package with the capability to provide substantially complete containment for a significantly extended lifetime would improve long-term performance.

An upgrade of the waste package design replaced the corrosion-allowance barrier with a corrosion-resistant barrier and was evaluated in the Supplement to the Draft EIS and this Final EIS. Several combinations of materials were considered for the inner and outer layers. The combination selected was an outer shell of nickel-based Alloy-22 corrosion-resistant material and a stainless-steel (Type 316NG) inner shell, which would provide structural strength and corrosion resistance.

E.2.2.12 Richards Barrier

A Richards Barrier would be a special type of backfill consisting of a fine-grained material, such as sand, covering a coarse-grained material, such as gravel. The coarse-grained material, in turn, would cover the waste package, with the fine-grained material acting as a cap or cover for the coarse-grained material. The Richards Barrier would use the difference in permeability between the two backfill materials to divert water. Water entering the emplacement drift would flow in the fine-grained material and not enter the coarse-grained material. The water would travel to the edge of the fine-grained material and reenter the surrounding rock mass through cracks. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.13 Diffusive Barrier/Getter Under the Waste Package

The diffusive barrier component would be a loose, dry, granular material placed in the intervening space beneath each waste package and above the bottom of the emplacement drift to a sufficient depth and degree of compaction that would form a restrictive barrier to seepage. The getter component, a fine-grained material with an affinity for radionuclides, would be mixed with a matrix material and dumped into the invert recess. The combined material would be placed around the structural supports of the waste package to eliminate voids when the waste package was emplaced. This design feature is no longer under active consideration because of uncertainties in the long-term performance improvement of the repository and uncertainties in the long-term effectiveness of the material (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.1).

E.2.2.14 Canistered Assemblies

Placing commercial spent nuclear fuel assemblies in canisters at the Waste Handling Building before inserting them into disposal containers would provide an additional barrier and further limit mobilization of radionuclides if the waste package was breached. The canisters would be fabricated from a corrosion-resistant material (for example, Alloy-22 or a zirconium alloy). There would be three general concepts for the placement of fuel assemblies in canisters: (1) Canisters could be designed to hold individual fuel assemblies; (2) Canisters could be designed to hold a few assemblies, and (3) A large canister could be designed to hold multiple fuel assemblies and fit one canister per waste package. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.15 Additives and Fillers

Waste package additives and fillers (henceforth referred to simply as fillers) are materials that could be placed in a loaded waste package to fill the void spaces. These materials could have the following benefits for performance of the engineered barrier system: (1) retardation of radionuclide release from a breached waste package by absorbing radionuclides and providing resistance to advective transport; (2) displacement of the moderator from the interior of the waste package to provide additional defense-in-depth for criticality control; and (3) limitation on the amount of oxygen available for waste form alternation. In addition, various waste package filler options could provide such benefits as serving as a mechanical packing to inhibit movement of the waste form in the package, creating a barrier to the release of particulate radionuclides during a design-basis event, or providing cathodic protection of fuel and basket material. The disadvantages of additives and fillers include adding weight to the waste package, introducing the potential for additional corrosion or chemical reaction, and complicating the removal of material from the waste package if necessary following retrieval. This design feature is not considered necessary to meet the design and performance criteria for the flexible design, but it remains as a potential additional design feature if needed to broaden the scope of defense-in-depth (DIRS 107292-CRWMS M&O 1999, Section 5.1.5.1).

E.2.2.16 Ground Support Options

Ground support in the repository is intended to ensure drift stability before closure. The selection of ground support options could affect repository waste isolation performance. Consideration of ground support options included functional requirements for ground support, the use of either concrete or steel-lined systems, and the feasibility of using an unlined drift ground support system with grouted rock bolts.

A concrete lining has been studied for its structural/mechanical behavior and subjected to the load conditions expected of emplacement drifts. A concrete lining in the emplacement drifts was evaluated in the impact analysis for the Draft EIS. However, a number of postclosure performance assessment issues related to the presence of concrete in the emplacement drift environment have been identified.

An all-steel ground support system (for example, steel sets with partial or full steel lagging) has been considered a viable ground support candidate for emplacement drifts. The use of an all-steel lining system would provide a way to limit or eliminate the introduction of cementitious materials (that is, concrete, shotcrete, or grout), including organic compounds, into the emplacement drift environment. The potential for corrosion of steel subjected to the emplacement drift environment is a concern with this system. For the Supplement to the Draft EIS and this Final EIS, the all-steel ground support system for the emplacement drifts and a concrete liner support system for the main drifts and ventilation shafts were included as part of the Proposed Action.

E.2.2.17 Near-Field Rock Treatment

The function of rock treatment would be to limit the amount of water than could seep into the drift. The treatment would consist of injecting low-permeability grout into the cracks in a portion of the rock overlying each drift to lower the hydraulic conductivity of the rock in the treated zone. This would decrease seepage into the drift and thus reduce the amount of water that could contact the waste packages during postclosure. To meet seepage criteria, the rock treatment would have to perform while seepage toward the emplacement drift occurred.

Injection would start at least 6 meters (20 feet) above the drift crown and would form a zone at least 4 meters (13 feet) thick, extending at least 6 meters on each side of the drift. Injection would be through holes 2.5 to 5 centimeters (1 to 2 inches) in diameter drilled from inside each drift prior to waste emplacement. Injection pressures would not exceed a certain minimum pressure, selected to limit rock fracturing or joint opening. The candidate materials include Portland cement grout, sodium silicate, bentonite (a clay), and calcite. This design feature is no longer under active consideration because it had limited potential to improve postclosure repository performance and its cost was high (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.2).

E.2.2.18 Surface Modification

Surface modifications could be a way to significantly reduce or eliminate the amount of water that could seep into the mountain from the surface and reach the waste packages. Two modification options were considered. The first option (alluvium option) would be to alter the ground surface to encourage natural removal of water to the atmosphere by evaporation from the ground surface and deep water removal by transpiration from plants. To cover the mountain with alluvium, the surface of the mountain would be modified to prevent the alluvium from washing away. Ridge tops on the eastern flank of Yucca Mountain would be removed and the excavated rock placed in Solitario Canyon and Midway Valley or used to fill the alluvium borrow pit. The maximum slope of the ground surface remaining would be approximately 10 percent. Alluvium approximately 2 meters (7 feet) thick would be placed on the new surface and vegetation would be established.

The second option (drainage option) is to alter the surface drainage to promote the rapid runoff of surface water by removing the thin layer of alluvium on the hilltops and slopes to expose the bedrock. It has been shown that where the alluvium is thin, it retains the surface water and allows it to infiltrate the unsaturated zone. Where bedrock is exposed on slopes, water runs off rapidly and net infiltration is very small or reduced to zero. The thin alluvium layer would be stripped from the topographic surface above the repository footprint and a 300-meter (980-foot) buffer surrounding it. This design feature is no longer under active consideration since the lifetime of the alluvium layer was uncertain and the long-term effects of increased runoff could not be predicted. The feature also resulted in large short-term environmental impacts due to the extensive surface modification (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.3).

E.2.2.19 Repository Horizon Elevation

Two basic design concepts were considered for the repository horizon elevation feature. The first concept would be to relocate the repository to a higher evaluation. The higher elevation would be excavated in a single lithophysal unit, specifically the upper lithophysal unit. The second concept would be of a two-tier repository. This concept could allow for repository expansion if a decision was made to increase the waste inventory, provide performance improvements through thermal hydraulic effects, and increase flexibility in waste package emplacement strategies. This design feature is no longer under active consideration because further evaluation indicated severe construction problems including very steep access drifts, and the two-tier concept could not be shown to offer long-term performance improvement (DIRS 107292-CRWMS M&O 1999, Section 5.1.7.4).

E.2.2.20 Higher Thermal Loading

This feature would increase the thermal loading of the repository by placing the waste packages close together, thereby increasing the density of heat sources in the repository. Although the total heat would not increase, it would be more concentrated because the repository would occupy a smaller area. This closer packing of waste packages could be done in one of three ways. The emplacement drifts could be excavated closer to one another. The waste packages would be placed closer together in each drift, with the emplacement drifts at their original reference spacing. The third possibility combines the first two options, resulting in closely spaced waste packages in closely spaced drifts. In all cases, the increased number of waste packages in a given area would create a higher concentration of heat, resulting in a higher thermal load to a given area of the repository. This design feature is no longer under active consideration.

E.2.2.21 Dry Handling of Spent Fuel in the Waste Handling Building

A dry handling capability in the Waste Handling Building would facilitate the handling of fuel assemblies, canisters, and waste packages in a dry environment. In addition, it would provide dry storage facilities for the temporary storage of fuel assemblies to support blending. The Waste Handling Building design would include hot cells, transfer facilities, and isolated maintenance cells to support receipt of truck and rail transportation casks, unloading of fuel assemblies and canisters from casks, opening of dual-purpose canisters, unloading of fuel assemblies from dual-purpose canisters, transfer of fuel assemblies to and from dry storage vaults, loading of fuel assemblies into disposal containers, transfer of filled disposal containers to the disposal container cell for emplacement preparation, and preparation of the empty transportation cask and dual-purpose canisters for offsite shipment. Two identical dry assembly transfer system lines and one dry canister transfer system would support the planned throughput rate. The estimated capacity of the dry fuel storage system would be 5,000 MTHM to support blending of the waste such that no waste package exceeded 11.8 kilowatts. This design feature might be considered and evaluated further in the future.

E.2.2.21.1 *Potential Benefits*

The dry handling approach potentially would have several operational advantages over the wet handling approach. A significant advantage is that the estimated throughput rate for the dry handling system would be about a third higher than that for an equivalent wet system, which would increase operational flexibility. Liquid wastes and worker doses during operation would be reduced substantially with respect to the corresponding values for a wet system. The dry handling approach would eliminate the need for assembly cooling in the cask preparation step and for drying the assemblies prior to disposal container loading. Dry handling would also eliminate the need to dewater shipping casks after unloading. In general, it would be an advantage to eliminate some of the challenges associated with water in pools and wet handling.

E.2.2.21.2 *Potential Environmental Considerations*

The space required for the dry handling facility would be about the same as the space required for equivalent wet handling if commercial spent nuclear fuel blending was not needed. If commercial spent nuclear fuel blending was required, the dry handling/storage facility would be larger than the wet facility because the spent nuclear fuel stored dry would have to be spaced farther apart than in wet storage. Accordingly, DOE could have to expand the overall Waste Handling Building site to accommodate dry handling. The use of construction materials such as concrete and steel would increase for the dry handling facility. As mentioned above, the dry handling approach would reduce worker doses and the generation of liquid waste. Conversely, the cost of building the dry handling facilities would be higher but the operation costs would be equal or less than those for wet handling.

E.2.2.22 Site Access Road

A new site access road would enable more direct, efficient, and safe travel for personnel and transportation of materials. A conceptual plan for the new access road involves the construction of an approximately 32-kilometer (20-mile) section of roadway from Amargosa Valley (formerly known as Lathrop Wells) at U.S. Highway 95 near the southwest corner of the Nevada Test Site to the Yucca Mountain site. The road would run in a predominantly northerly direction parallel to Fortymile Wash and would terminate at the Yucca Mountain site in the vicinity of the North Portal. Figure E-1 shows the route being considered. The road would have two 3.7-meter (12-foot)-wide travel lanes, and 2.4-meter (8-foot)-wide shoulders, and would consist of a 15-centimeter (6-inch)-asphaltic concrete pavement over a 30-centimeter (12-inch) aggregate base. This design feature might be considered and evaluated further in the future.

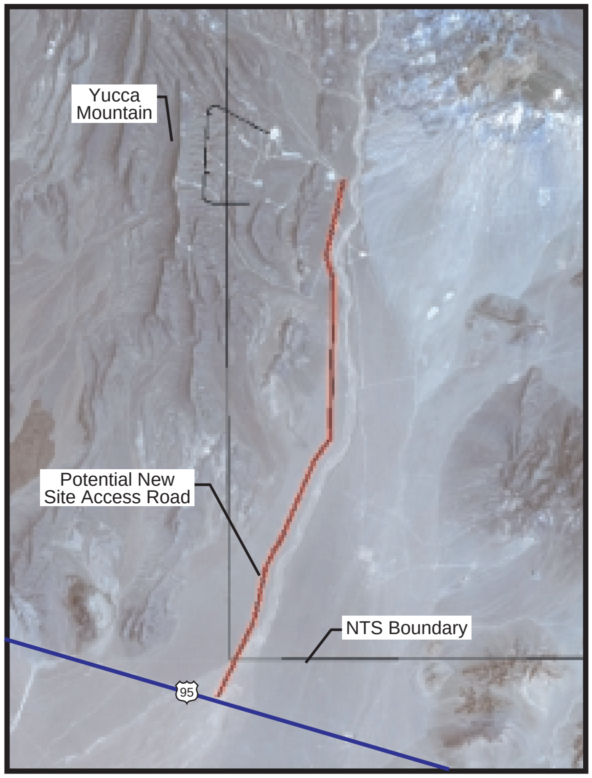

Figure E-1. Site access road.

E.2.2.22.1 *Potential Benefits*

The primary benefit from constructing a new site access road would be to facilitate more direct, efficient, and safe travel to the Yucca Mountain site. Current highway access to the Yucca Mountain site from the Las Vegas area to the east is by U.S. Highway 95 to the Mercury interchange near the southwest corner of the Nevada Test Site. From the Mercury interchange, the route travels about 110 kilometers (70 miles) to the Yucca Mountain site on existing roads that are old, narrow, and indirect, passing through about 10 intersections. Highway access from the west is by the existing Lathrop Wells Road for about 42 kilometers (26 miles) from U.S. 95 to the Yucca Mountain Site Central Support Site and then on to the site over about 27 kilometers (17 miles) of existing Nevada Test Site roads.

The new site access road would provide repository access from the Las Vegas area by travelling about 97 kilometers (60 miles) west past the Mercury interchange on U.S. 95 to the interchange at Amargosa Valley and then on the 32-kilometer (20-mile) section of newly constructed road to the repository site. Although this route would be about 16 kilometers (10 miles) longer than the existing route, it would be at least 10 to 20 percent faster and much safer, especially for transport vehicles carrying construction materials. Access to the repository site from the west would be directly from U.S. 95 on the 32-kilometer (20-mile)-long new access road and would be about half the distance of using the existing Nevada Test Site roads.

E.2.2.22.2 *Potential Environmental Considerations*

DOE would have to evaluate the environmental impacts of constructing the site access road. The 32-kilometer (20-mile)-long road would have about 12-meter (40-foot)-wide pavement and an assumed standard 3:1 slope and drainage beyond the paved shoulders, so the total road width would be about

24 meters (80 feet). The minimum total permanently disturbed area resulting from the construction of the road would be about 0.87 square kilometer (194 acres). Additional temporary disturbed area could occur from construction facilities, borrow pits, and laydown areas, which could total as much as 0.081 square kilometer (20 acres). These areas would be evaluated in an environmental survey to ensure that the impacts of constructing the access road were acceptable. The survey would focus on land use and ownership, cultural resources, hydrology, soils, and biological resources in and along the route. In addition, it would consider air quality, the safety of workers travelling the road, socioeconomic issues, and construction materials on a comparative basis with current routes.

E.3 Enhanced Design Alternatives

Enhanced Design Alternatives are combinations of the alternatives and design features described in the preceding sections. These concepts were developed to cover a range of potential repository designs as part of the License Application Design Selection Process described in Section E.1.2. Enhanced Design Alternatives are intended to be improvements to the basic design alternatives discussed in Section E.2. Five Enhanced Design Alternatives were developed in the License Application Design Selection project. As stated in Section E.1.2.2, DOE chose Enhanced Design Alternative II for continued development and as the basis for the Final EIS analysis. For a description of the other Enhanced Design Alternatives, the methods used to evaluate them, and the results of the evaluations see the final *License Application Design Selection Report* (DIRS 107292-CRWMS M&O 1999, all).

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Appendix F

Human Health Impacts Primer and Details for Estimating Health Impacts to Workers from Yucca Mountain Repository Operations

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APPENDIX F. HUMAN HEALTH IMPACTS PRIMER AND DETAILS FOR ESTIMATING HEALTH IMPACTS TO WORKERS FROM YUCCA MOUNTAIN REPOSITORY OPERATIONS

Section F.1 of this appendix contains information that supports the estimates of human health and safety impacts in this environmental impact statement (EIS). Specifically, Section F.1 is a primer that explains the natures of radiation and toxic materials, where radiation comes from in the context of the radiological impacts discussed in this EIS, how radiation interacts with the human body to produce health impacts, and how toxic materials interact with the body to produce health impacts. The remainder of the appendix discusses the methodology that was used to estimate worker health impacts and the input data to the analysis, and presents the detailed results of the analysis of worker health impacts.

Section F.2 discusses the methodology and data that the U.S. Department of Energy (DOE) used to estimate worker health and safety impacts for the Proposed Action. It also discusses the detailed results of the impact analysis.

Section F.3 discusses the methodologies and data that DOE used to estimate worker health and safety impacts for Inventory Modules 1 and 2. It also discusses the detailed results of the impact analysis.

Section F.4 discusses the methodology and data that DOE used to estimate worker health and safety impacts for retrieval, should such action become necessary. In addition, it discusses the detailed results from the impact analysis.

Radiological impacts to the public from operations at the Yucca Mountain site could result from release of naturally occurring radon-222 and its decay products in the ventilation exhaust from the subsurface repository operations. The methodology and input data used in the estimates of radiological dose to the public are presented in Appendix G, Air Quality. Outside of the radiation primer, health impacts to the public are not treated in this appendix.

F.1 Human Health Impacts from Exposure to Radioactive and Toxic Materials

This section introduces the concepts of human health impacts as a result of exposure to radiation and potentially toxic materials.

F.1.1 RADIATION AND HUMAN HEALTH

F.1.1.1 Radiation

Radiation is the emission and propagation of energy through space or through a material in the form of waves or bundles of energy called photons, or in the form of high-energy subatomic particles. Radiation generally results from atomic or subatomic processes that occur naturally. The most common kind of radiation is *electromagnetic radiation,* which is transmitted as photons. Electromagnetic radiation is emitted over a range of wavelengths and energies. We are most commonly aware of visible light, which is part of the spectrum of electromagnetic radiation. Radiation of longer wavelengths and lower energy includes infrared radiation, which heats material when the material and the radiation interact, and radio waves. Electromagnetic radiation of shorter wavelengths and higher energy (which are more penetrating) includes ultraviolet radiation, which causes sunburn, X-rays, and gamma radiation.

RADIATION

Radiation occurs on Earth in many forms, either naturally or as the result of human activities. Natural forms include light, heat from the sun, and the decay of unstable radioactive elements in the Earth and the environment. Some elements that exist naturally in the human body and in the environment are radioactive and emit ionizing radiation. For example, one of the naturally occurring isotopes of potassium (essential for health) is radioactive. In addition, isotopes of the naturally occurring uranium and thorium decay series are widespread in the human environment. Human activities have also led to sources of ionizing radiation for various uses, such as diagnostic and therapeutic medicine and nondestructive testing of pipes and welds. Nuclear power generation produces ionizing radiation as well as radioactive materials, which undergo radioactive decay and can continue to emit ionizing radiation for long periods of time.

Ionizing radiation is radiation that has sufficient energy to displace electrons from atoms or molecules to create ions. It can be electromagnetic (for example, X-rays or gamma radiation) or subatomic particles (for example, alpha and beta radiation). The ions have the ability to interact with other atoms or molecules; in biological systems, this interaction can cause damage in the tissue or organism.

F.1.1.2 Radioactivity, Ionizing Radiation, Radioactive Decay, and Fission

Radioactivity is the property or characteristic of an unstable atom to undergo spontaneous transformation (to *disintegrate* or *decay*) with the emission of energy as radiation. Usually the emitted radiation is ionizing radiation. The result of the process, called *radioactive decay*, is the transformation of an unstable atom (a *radionuclide*) into a different atom, accompanied by the release of energy (as radiation) as the atom reaches a more stable, lower energy configuration.

Radioactive decay produces three main types of ionizing radiation—alpha particles, beta particles, and gamma or X-rays—but our senses cannot detect them. These types of ionizing radiation can have different characteristics and levels of energy and, thus, varying abilities to penetrate and interact with atoms in the human body. Because each type has different characteristics, each requires different amounts of material to stop (shield) the radiation. Alpha particles are the least penetrating and can be stopped by a thin layer of material such as a single sheet of paper. However, if radioactive atoms (called radionuclides) emit alpha particles in the body when they decay, there is a concentrated deposition of energy near the point where the radioactive decay occurs. Shielding for beta particles requires thicker layers of material such as several reams of paper or several inches of wood or water. Shielding from gamma rays, which are highly penetrating, requires very thick material such as several inches to several feet of heavy material (for example, concrete or lead). Deposition of the energy by gamma rays is dispersed across the body in contrast to the local energy deposition by an alpha particle. In fact, some gamma radiation will pass through the body without interacting with it.

In a nuclear reactor, heavy atoms such as uranium and plutonium can undergo another process, called *fission*, after the absorption of a subatomic particle (usually a neutron). In fission, a heavy atom splits into two lighter atoms and releases energy in the form of radiation and the kinetic energy of the two new lighter atoms. The new lighter atoms are called fission products. The fission products are usually unstable and undergo radioactive decay to reach a more stable state.

Some of the heavy atoms might not fission after absorbing a subatomic particle. Rather, a new nucleus is formed that tends to be unstable (like fission products) and undergo radioactive decay.

The radioactive decay of fission products and unstable heavy atoms is the source of the radiation from spent nuclear fuel and high-level radioactive waste that makes these materials hazardous in terms of potential human health impacts.

F.1.1.3 Exposure to Radiation and Radiation Dose

Radiation that originates outside an individual's body is called *external* or *direct radiation*. Such radiation can come from an X-ray machine or from *radioactive materials* (materials or substances that contain radionuclides), such as radioactive waste or radionuclides in soil. *Internal radiation* originates inside a person's body following intake of radioactive material or radionuclides through ingestion or inhalation. Once in the body, the fate of a radioactive material is determined by its chemical behavior and how it is metabolized. If the material is soluble, it might be dissolved in bodily fluids and be transported to and deposited in various body organs; if it is insoluble, it might move rapidly through the gastrointestinal tract or be deposited in the lungs.

Exposure to ionizing radiation is expressed in terms of *absorbed dose,* which is the amount of energy imparted to matter per unit mass. Often simply called *dose,* it is a fundamental concept in measuring and quantifying the effects of exposure to radiation. The unit of absorbed dose is the *rad.* The different types of radiation mentioned above have different effects in damaging the cells of biological systems. *Dose equivalent* is a concept that considers (1) the absorbed dose and (2) the relative effectiveness of the type of ionizing radiation in damaging biological systems, using a radiation-specific quality factor. The unit of dose equivalent is the *rem.* In quantifying the effects of radiation on humans, other types of concepts are also used. The concept of *effective dose equivalent* is used to quantify effects of radionuclides in the body. It involves estimating the susceptibility of the different tissue in the body to radiation to produce a tissue-specific weighting factor. The weighting factor is based on the susceptibility of that tissue to cancer. The sum of the products of each affected tissue's estimated dose equivalent multiplied by its specific weighting factor is the *effective dose equivalent.* The potential effects from a one-time ingestion or inhalation of radioactive material are calculated over a period of 50 years to account for radionuclides that have long half-lives and long residence time in the body. The result is called the *committed effective dose equivalent.* The unit of effective dose equivalent is also the *rem. Total effective dose equivalent* is the sum of the committed effective dose equivalent from radionuclides in the body plus the dose equivalent from radiation sources external to the body (also in rem). All estimates of dose presented in this environmental impact statement, unless specifically noted as something else, are total effective dose equivalents, which are quantified in terms of rem or millirem (which is one one-thousandth of a rem).

More detailed information on the concepts of radiation dose and dose equivalent are presented in publications of the National Council on Radiation Protection and Measurements (DIRS 101857-NCRP 1993, p. 16-25) and the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 4-11). The DOE implementation guide for occupational exposure assessment (DIRS 138429-DOE 1998, pp. 3 to 11) also provides additional information.

The factors used to convert estimates of radionuclide intake (by inhalation or ingestion) to dose are called *dose conversion factors*. The National Council on Radiation Protection and Measurements and Federal agencies such

FISSION

Fission is the process whereby a large nucleus (for example, uranium-235) absorbs a neutron, becomes unstable, and splits into two fragments, resulting in the release of large amounts of energy per unit of mass. Each fission releases an average of two or three neutrons that can go on to produce fissions in nearby nuclei. If one or more of the released neutrons on the average causes additional fissions, the process keeps repeating. The result is a self-sustaining chain reaction and a condition called criticality. When the energy released in fission is controlled (as in a nuclear reactor), it can be used for various benefits such as to propel submarines or to provide electricity that can light and heat homes.

as the U.S. Environmental Protection Agency publish these factors (DIRS 101882 and 101883-NCRP 1996, all; DIRS 107684-Eckerman and Ryman 1993, all; DIRS 101069-Eckerman, Wolbarst, and Richardson 1988, all). They are based on original recommendations of the International Commission on Radiological Protection (DIRS 101075-ICRP 1977, all).

The radiation dose to an individual or to a group of people can be expressed as the total dose received or as a dose rate, which is dose per unit time (usually an hour or a year).

Collective dose is the total dose to an exposed population. *Person-rem* is the unit of collective dose. Collective dose is calculated by summing the individual dose to each member of a population. For example, if 100 workers each received 0.1 rem, then the collective dose would be 10 person-rem (100 × 0.1 rem).

F.1.1.4 Background Radiation from Natural Sources

Nationwide, on average, members of the public are exposed to approximately 360 millirem per year from natural and manmade sources (DIRS 101855-NCRP 1987, p. 53). Figure F-1 shows the relative contributions by radiation sources to people living in the United States (DIRS 101855-NCRP 1987, p. 55).

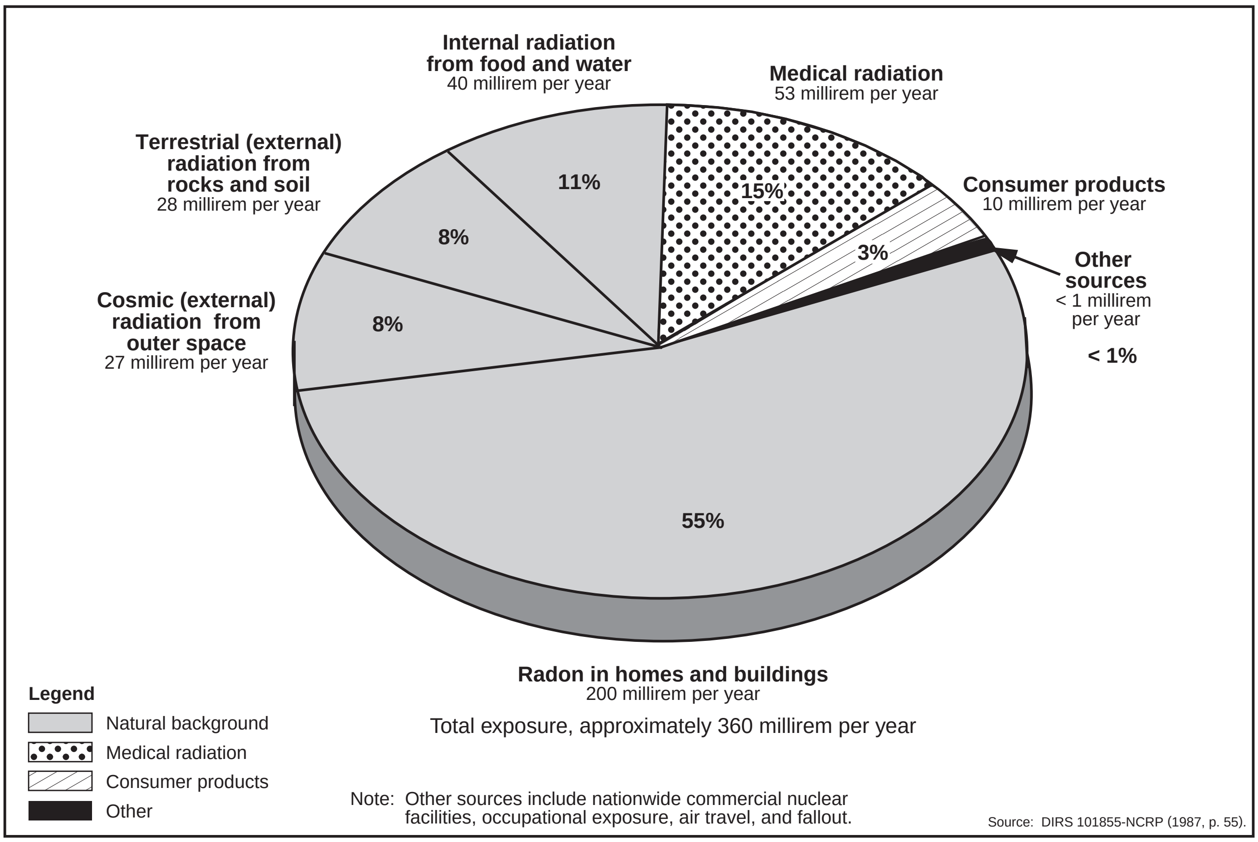

Figure F-1. Sources of radiation exposure.

The estimated average annual dose rate from natural sources is only about 300 millirem per year. This represents about 80 percent of the annual dose received by an average member of the U.S. public. The largest natural sources are radon-222 and its radioactive decay products in homes and buildings, which contribute about 200 millirem per year. Additional natural sources include radioactive material in the Earth (primarily the uranium and thorium decay series, and potassium-40) and cosmic rays from space filtered through the atmosphere. With respect to exposures resulting from human activities, medical exposure accounts for 15 percent of the annual dose, and the combined doses from weapons testing fallout, consumer and industrial products, and air travel (cosmic radiation) account for the remaining 3 percent of the total annual dose. Nuclear fuel-cycle facilities contribute less than 0.1 percent (0.005 millirem per year per person) of the total dose (DIRS 101855-NCRP 1987, pp. 52 to 56).

F.1.1.5 Impacts to Human Health from Exposure to Radiation

Exposures to radiation or radionuclides are often categorized as being either acute or chronic. Acute exposures occur over a short period. Chronic exposures occur over longer periods (months to years); they are usually continuous over the period, even though the dose rate might vary. For a given dose of radiation, chronic radiation exposure is usually less harmful to the body than an acute exposure because the dose rate (dose per unit time, such as rem per hour) is lower, providing more opportunity for the body to repair the damaged cells (DIRS 101836-ICRP 1991, p. 107).

Acute Exposures at High Dose Rates

Exposure to high levels of radiation at high dose rates over a short period, typically 24 hours or less, can result in acute radiation effects, called *radiation sickness*. If the dose is sufficiently high, death is the eventual result of radiation sickness. At lower doses, recovery can occur, depending on the dose rate and the extent of medical intervention. External (rather than internal) exposures are generally of most concern during a high dose rate, acute exposure event. In such a situation, the biological effects depend more on absorbed dose received than on dose equivalent (DIRS 155674-Hall 1978, p. 106-107).

For external exposures, minor changes in blood characteristics might occur at doses in the range of 25 to 50 rad. The external symptoms of radiation sickness begin to appear when exposures are about 100 rads or greater. Symptoms can include anorexia, nausea, and vomiting. More severe symptoms occur at higher doses and can include death at doses higher than 200 to 300 rad of total body irradiation, depending on the level of medical treatment received. Information on the effects on humans of acute exposures can be obtained from studies of the survivors of the Hiroshima and Nagasaki bombings during World War II and from studies following a number of acute external exposure events (DIRS 102185-Mettler and Moseley 1985, pp. 276-280).

Other effects can follow acute exposures to specific portions of the body. Temporary sterility in men and women has been observed following irradiation of the gonads to doses in the tens to hundreds of rads. Erythema (reddening of the skin) can occur when the skin is exposed to high doses of low-energy radiation (DIRS 108074-Cember 1983, pp. 181-184). In patients treated with external radiation beams for cancer therapy, pulmonary fibrosis or other lung disorders can occur.

As noted above, acute exposures have occurred following detonations of nuclear weapons, both in wartime and during weapons testing, and in other events involving testing of nuclear materials. In addition, there is a potential for acute exposures in the event of an accident at an operating nuclear electric generating station, although Nuclear Regulatory Commission regulations require that the electric utilities design their stations such that these events are extremely unlikely. Such exposures could occur only if there were a highly unlikely failure of the containment vessel surrounding the nuclear reactor and a large release of fission products from the generating station following an accident.

In contrast, accidents during the shipment of spent nuclear fuel or high-level radioactive waste do not have the potential to release sufficient fission products to lead to acute exposures that might immediately threaten the life of the surrounding public. This is because the fission product source term in the spent nuclear fuel would have decayed by a factor of 10,000 or more by the time DOE shipped the material to the proposed repository. Thus, there would not be sufficient energy generated by the fission products in the spent nuclear fuel being shipped to melt the fuel elements and vaporize fission products, as postulated for an accident at an operating nuclear electric generating station.

In the highly unlikely event of an accident during shipment of spent nuclear fuel that is severe enough to breach the shipping cask and rupture the contained spent nuclear fuel, there would be a potential to release fission products to the environment, as discussed in Chapter 6. Following such an event, the principal human exposure pathways would be inhalation or ingestion of released long-lived radioactive fission products. Such an intake of radioactivity could result in a continuing chronic exposure to an individual, but not an acute exposure. Continuing chronic exposures are discussed in the following subsection.

Exposures at Low Dose Rates Including Chronic Exposures

The radiation dose estimates discussed in this EIS are associated with exposure to radiation at low dose rates. Such exposures can be chronic (continuous or nearly continuous), such as those to workers during repository operation, or those to members of the public from the low concentrations of radon-222 and its decay products released in the exhaust from the repository. In some instances, exposures to low levels of radiation would be intermittent (for example, infrequent exposures to an individual from radiation emitted from shipping casks as they are transported). Cancer induction is the principal potential risk to human health from exposure to low levels of radiation. This cancer induction is a statistical process, however, in that exposure to radiation conveys only a chance of incurring cancer, not a certainty. Further, cancer induction in individuals can occur from other causes, such as exposure to chemical agents or natural causes.

Health effects other than fatal cancers can result from exposure to radiation. The International Commission on Radiological Protection suggested the use of detriment weighting factors that consider the curability rate of nonfatal cancers and the reduced quality of life associated with nonfatal cancers and possible hereditary effects (DIRS 101836-ICRP 1991, p. 22). These effects are very difficult to quantify because nonfatal cancers and hereditary effects can be induced from several other causes. Further, hereditary effects have not been demonstrated in humans as a result of exposure to radiation, even in the Japanese atomic bomb survivor population (DIRS 157315-Boice 1990, all). The risk of both of these life-detriment factors, taken together, is believed to be much smaller than the fatal cancer risk. In addition, the National Research Council Committee on Biological Effects of Ionizing Radiation has stated that cancer induction is the most important somatic effect (DIRS 153007-National Research Council 1980, pp. 2 and 136). While DOE recognizes the existence of health effects other than fatal cancers, DOE acknowledges that these effects are extremely difficult to quantify because of all the other factors in life that can cause these effects; accordingly, these effects are not included in the Final EIS. The Final EIS does present human health effects from exposure to radiation based on the potential for induction of fatal cancers.

There are no data that show a clear link between low levels of radiation exposure and cancer. Most of the data on induction of cancer by radiation comes from studying relatively small numbers of people who have received acute exposures to higher doses of radiation (more than 10 rem over a short period), such as atomic bomb survivors. Utilizing the information obtained at these higher exposure rates to estimate effects at low dose rates requires the assumption of a relationship between the overall exposure and the probability of a health effect. The approach generally used is called the *linear dose effect hypothesis*. This concept is shown in Figure F-2, which uses a hypothetical line to extrapolate dose effects at high dose rates to what might occur at low dose rates. It is obvious from the figure that more than one line or curve could be used to fit the data, all of which was obtained at dose rates above 10 rem. Because there is not a statistically significant number of observed effects in the low-dose-rate region, radiation protection organizations, such as the International Commission on Radiological Protection, have assumed a linear-no-threshold response (DIRS 101857-NCRP 1993, p. 112; DIRS 101836-ICRP 1991, p. 22). Under this

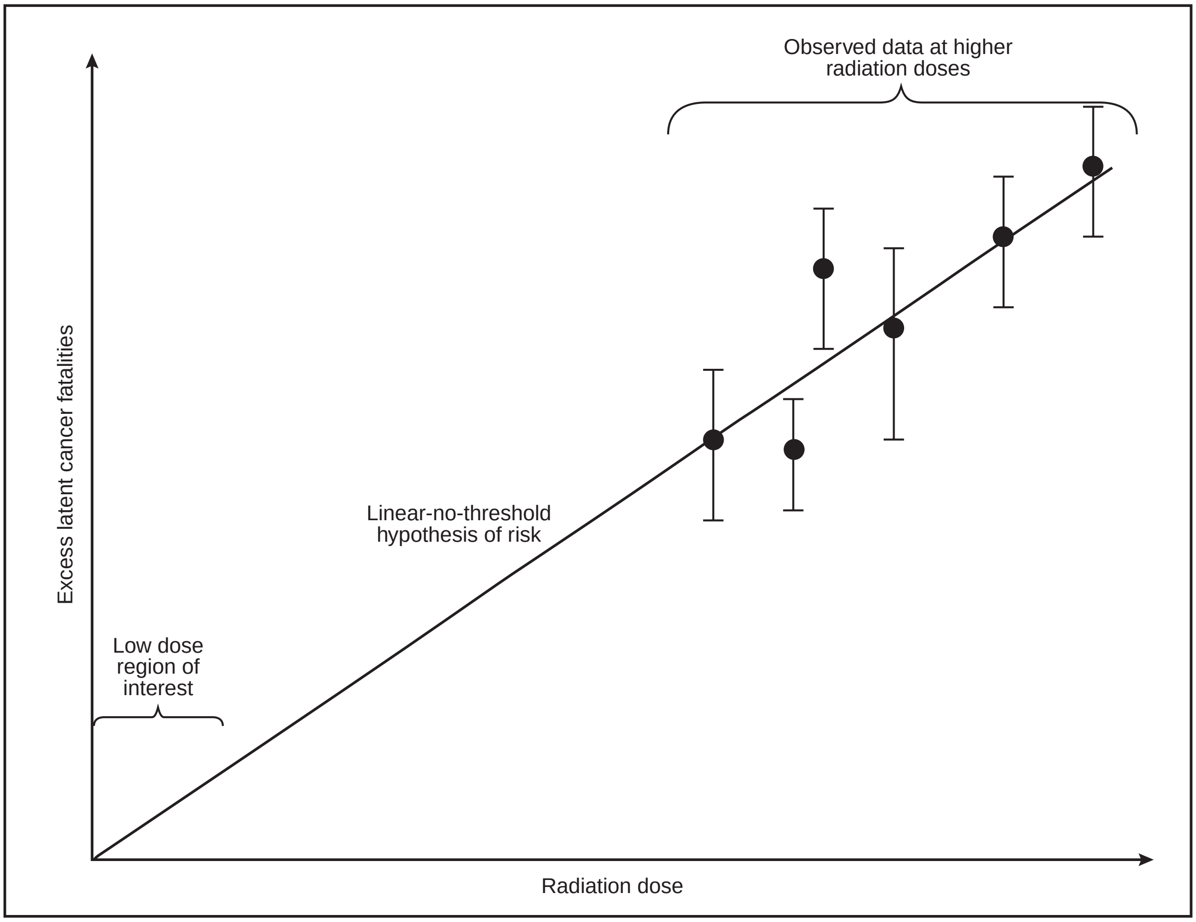

Figure F-2. Assumed linear hypothesis of radiation risks at low doses.

hypothesis, all radiation exposure, no matter how small, involves some risk for inducing cancer and risk increases in proportion to the received dose.

In this EIS, radiological health impacts are expressed as incremental changes in the number of expected fatal cancers (latent cancer fatalities) for the offsite public and for repository workers. Because of the uncertainties in dose response in the low-dose-rate region, the impact estimates provide a general indication of possible health impacts (the potential number of induced cancers) but should not be interpreted as the exact number of induced cancers or as an indication of the individuals in whom cancers might be induced.

Factors Used in this EIS To Convert Accumulated Doses to Health Effects

The factors used to estimate potential health impacts from radiation exposures at low dose rates are based on the dose-to-health-effects conversion factors recommended by the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 22). The Commission estimated that, for the general population, a collective dose of 1 person-rem could yield about 0.0005 excess latent cancer fatality in the exposed population. Because young children are more sensitive to radiation than adults, and because children make up a large part of the general population, the risk conversion factor for the general population is greater than that for a population that includes only workers. Thus, a separate, smaller dose-to-risk conversion factor was recommended for workers (only people older than 18 were considered). The risk factor for workers recommended by the National Council on Radiation Protection and Measurements is 0.0004 excess latent cancer fatality per rem of population exposure (DIRS 101857-NCRP 1993, p. 3).

These concepts can be used to estimate the effects of exposing a population to radiation. For example, if each of 100,000 people was exposed only to background radiation (0.3 rem per year), 15 latent cancer fatalities would be estimated to occur as a result of 1 year of exposure (100,000 persons multiplied by 0.3 rem per year multiplied by 0.0005 latent cancer fatality per person-rem equals 15 latent cancer fatalities per year).

Calculations of the number of latent cancer fatalities associated with radiation exposure normally do not yield whole numbers and, especially in environmental applications, can yield numbers less than 1.0. For example, if each of 100,000 people was exposed to a total dose of 1 millirem (0.001 rem), the population dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons multiplied by 0.001 rem multiplied by 0.0005 latent cancer fatality per person-rem equals 0.05 latent cancer fatality).

The average number of deaths that would result if the same exposure situation applied to many different groups of 100,000 people is 0.05 for each such group. In most groups, nobody (zero people) would incur a latent cancer fatality from the 1-millirem dose to each member of the group. In a small fraction of the groups, one latent fatal cancer would result; in exceptionally few groups, two or more latent fatal cancers would occur. The average number of deaths over all the groups would be 0.05 latent fatal cancer (just as the average of 0, 0, 0, and 1 is 0.25). The most likely outcome is no latent cancer fatalities in these different groups.

The same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation of 0.3 rem per year over a lifetime. The corresponding likelihood that an individual would experience a radiation-induced latent cancer fatality in that individual's 70-year lifetime is:

$$
\begin{aligned}
\text{Latent cancer fatality} \quad &= 1 \text{ person} \times 0.3 \text{ rem per year} \times 70 \text{ years} \\
&\times 0.0005 \text{ latent cancer fatality per person-rem} \\
&= 0.011 \text{ latent cancer fatality.}
\end{aligned}
$$

This result must be interpreted in a statistical sense; that is, the estimated effect of background radiation exposure on the exposed individual would produce a 1.1-percent chance that the individual would incur a latent fatal cancer over a 70-year lifetime.

Uncertainty in the Risk Factors for Estimating Health Effects from Low Dose Rate Exposures

The National Council on Radiation Protection and Measurements has stated, "This work indicates that given the sources of uncertainties considered here, together with an allowance for unspecified uncertainties, the values for the lifetime risk can range from about one-fourth or so to about twice the nominal values" (DIRS 101884-NCRP 1997, p. 75). These uncertainties are due, in part, to the fact that the epidemiological studies have been unable to demonstrate that adverse health effects have occurred in individuals exposed to small chronic doses of radiation (less than 10 rem per year) over many years, and to the fact that the extent to which cellular repair mechanisms reduce the likelihood of cancers is unknown. Therefore, the uncertainties indicate that the values used in this EIS probably overestimate the impacts that could occur.

The Environmental Protection Agency recently published an age-specific risk factor of 5.75 chances in 10 million per millirem for fatal cancer (DIRS 153733-EPA 2000, Table 7.3, p. 179). However, DOE currently uses the value of 5.0 and 4.0 chances in 10 million per millirem for fatal cancer for members of the public and workers, respectively, as recommended by the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 22). When recommending these risk factors, the International Commission on Radiological Protection also expressed the desirability, for purposes of radiation protection, of using the same nominal risk factors for both men and women and for a representative population with wide ranges in age. The Commission stated that although there are differences between the sexes and populations of different age-specific mortality rates, these differences are not so large as to necessitate the use of different nominal risk factors. However, the higher risk factor for members of the public compared to that recommended for workers accounts for the fact that children comprise a relatively large part of the population and are more sensitive to the effects of radiation (cancer induction) than adults. Although the embryo-fetus is more radiosensitive (with a radiation risk factor about two times that for the whole population), it is protected by the body of the mother and comprises a small part of the overall population. Pregnant women are not unduly radiosensitive, especially to low levels of radiation.

Both the Environmental Protection Agency and DOE recognize that there are large uncertainties associated with these risk factors, as expressed by the National Council on Radiation Protection and Measurements comment on the result of their uncertainty analysis in the risk coefficients that ". . . show a range (90 percent confidence intervals) of uncertainty values for the lifetime risk for both a population of all ages and an adult worker population from about a factor of 2.5 to 3 below and above the 50th percentile value" (DIRS 101884-NCRP 1997, p. 74). DOE believes that the 15-percent difference in these risk factors is well within other uncertainties and would provide little additional information to the decisionmaking process that this document informs.

Perspectives on Risk

While the risk factors cited above are useful for calculations, comparing them to other risks helps to interpret their meaning. For example, according to statistics published by the Centers for Disease Control, during 1995 the death rate due to cancer in Nevada was 202 cancer deaths per 100,000 persons. The death rate from all causes during that same year was 828 deaths per 100,000; therefore, cancer was responsible for 24 percent of deaths during 1998 (DIRS 153066-Murphy 2000, p. 83).

The long-term risk from exposure to radiation can be placed in perspective by comparison to other risks that are encountered on a daily basis. One method for comparison is the *Loss of Life Expectancy*, which is an estimate of the average number of days of life lost for a given risk factor for a population.

Table F-1 lists Loss of Life Expectancy values for a variety of activities and circumstances. At the bottom of the table is the estimate of Loss of Life Expectancy for several different radiation exposure scenarios.

As discussed in the preceding section, the risk factor (and hence the Loss of Life Expectancy) for radiation exposure is based on an assumption that all radiation exposure carries some risk, even though that assumption has not been proven and might overestimate the true risk from low-level exposure.

F.1.1.6 Exposures from Naturally Occurring Radionuclides in the Subsurface Environment

The estimates of worker doses from inhalation of radon-222 and its decay products while in the subsurface environment and from the ambient radiation fields in the subsurface environment were based on measurements taken in the existing Exploratory Studies Facility drifts. The measurements and the annual dose rates derived from them are discussed below.

Table F-1. Loss of Life Expectancy for causes of death for average citizens of the United States.[a]

Risk factor	Loss of life expectancy (days)
Disease	
Cardiovascular diseases	2,043
Cancer – all types	1,247
Chronic pulmonary	164
Pneumonia	103
Diabetes	82
Tuberculosis	4.7
Influenza	2.3
Accidents	
Motor vehicle accidents	207
Homicide	93
Accidents at home	74
Accidents at work	60
Agriculture	320
Construction	227
Services	27
Radiation exposure	
Lifetime of continuous exposure (100 millirem per year)	15[b]
Single acute exposure of 1 millirem	0.002[b]
Single acute exposure of 1,000 millirem	2.3[b]

a. Tabulated by DIRS 155797-Cohen (1991, Table 3, p. 319).
b. Adapted from methodology presented by DIRS 155797-Cohen (1991, all).

Annual Dose Rate for Subsurface Facility Worker from Inhalation of Radon-222

The annual dose rate for a subsurface worker from inhalation of radon-222 and its decay products was estimated using information developed from radon concentration observations made in the Exploratory Studies Facility subsurface areas during site characterization and subsequent analyses of this data. Two reports (DIRS 152046-DOE 2000, all; DIRS 154176-CRWMS M&O 2000, all) have significantly expanded the available information on radon-222 flux into the repository, radon concentrations in the repository atmosphere, and radon releases from the repository. Additional information on radon release is in Appendix G, Section G.2.3.1.

Recent investigations of radon levels in the repository have led to estimates of radon exposure in Working Level units (DIRS 154176-CRWMS M&O 2000, Attachment 4). The Working Level is the common unit for expressing radon decay product exposure rates. The Working Level was originally developed for use in uranium mines but now is used for environmental exposures as well. Numerically, the Working Level is any combination of short-lived decay products in 1 liter of air that will result in the emission of 1.3×10^5 million electron volts of potential alpha energy. When radon is in complete equilibrium with its short-lived decay products, one Working Level equals 100 picocuries per liter (DIRS 153691-NCRP 1988, p. 17); that is, 100 picocuries per liter each of radon-222 and short-lived decay products polonium-218, lead-214, bismuth-214, and polonium-214. The advantage of the Working Level concept is that different equilibrium levels and different concentrations of radon decay products can be expressed and compared in a common unit. Differences in the activity concentrations between radon-222 and the short-lived decay products are considered using an equilibrium factor (DIRS 103279-ICRP 1994, p. 4). The degree of equilibrium is a critical factor for estimating inhalation exposure and is as important as the radon concentration itself (DIRS 153691-NCRP 1998, p. 19). The Working Level unit considers this factor.

The exposure of workers can be expressed in units of Working-Level Months, which is an exposure rate of 1 Working Level for a working month of 170 hours (DIRS 153691-NCRP 1988, p. 17). Working-Level Months can be converted to more familiar dose units of millirem or rem using a conversion factor of 0.5 rem (500 millirem) per Working-Level Month for inhalation of radon decay products by workers (DIRS 103279-ICRP 1994, p. 24). This dose conversion factor corresponds to 0.029 millirem per picocurie per liter per hour for radon decay products in complete equilibrium with the radon-222 parent (DIRS 103279-ICRP 1994, p. 5).

Average hourly dose rates were estimated for workers in the access mains and ramps, the emplacement drifts and similar 5.5-meter- (18-foot)- diameter drifts, and the overall repository with and without concrete liners, which would reduce the radon flux into the repository. The 5.5-meter drifts would not have concrete liners. These would be the main areas of the repository occupied by workers. Hourly dose rate estimates were developed for involved and noninvolved workers based on their likely work locations, which would also depend on the project phase or activity. Estimated hourly dose rates for involved and noninvolved workers, as well as estimates of the annual dose from radon based on 2,000 hours of occupational exposure in the repository, are listed in Table F-2.

Table F-2. Estimated dose rates to subsurface workers from inhalation of radon.[a]

Project phase and activity	Hourly dose rate (millirem per hour)	Annual dose rate (millirem per year)[b]
Construction		
Involved worker	0.10	200
Noninvolved worker	0.03	60
Operation and Monitoring		
Development		
Involved worker	0.10	200
Noninvolved worker	0.03	60
Emplacement		
Involved worker	0.06	120
Noninvolved worker	0.010	20
Monitoring		
Involved worker	0.050	100
Noninvolved worker	0.010	20
Closure		
Involved worker	0.010	20
Noninvolved worker	0.010	20

a. Numbers are rounded to two significant figures.
b. Based on 2,000 hours per year of occupational exposure in the repository.

In general, workers spending time in subsurface areas without concrete liners and with ventilation flow would have the highest exposures to radon and its decay products. These would be the involved workers during the construction phase and during the drift development period of the operation and monitoring phase. Noninvolved workers would spend more time in the access mains and ramps, with correspondingly less exposure from inhalation of radon decay products. By the end of the development period, all concrete liners would be in place, and exposures to radon decay products would be lower for workers during monitoring and closure. Involved workers during the monitoring period would receive moderate doses because they would be in all areas of the repository, including areas with exhaust from unlined drifts [such as emplacement drifts and other 5.5-meter (18-foot)-diameter drifts].

Annual Dose for Subsurface Facility Worker from Ambient External Radiation in Drifts

Workers in the subsurface facility would be exposed to external radiation from naturally occurring radionuclides in the rock. Measured exposure rates for the subsurface facility ranged from 0.014 to 0.038

millirem per hour (DIRS 104544-CRWMS M&O 1999, p. 12). As for inhalation dose estimates, the analysis assumed an underground exposure time of 2,000 hours per year. The estimated dose range to a worker in the repository from ambient external radiation would be from 28 to 76 millirem per year, with the center of the range being 50 millirem per year. This central estimate was used in this appendix for calculating worker dose estimates from ambient external radiation.

F.1.2 EXPOSURE TO TOXIC OR HAZARDOUS MATERIALS

When certain natural or manmade materials or substances have harmful effects that are not random or do not occur solely at the site of contact, the materials or substances are described as toxic. Toxicology is the branch of science dealing with the toxic effects that chemicals or other substances might have on living organisms.

Chemicals can be toxic for many reasons, including their ability to cause cancer, to harm or destroy tissue or organs, or to harm body systems such as the reproductive, immune, blood-forming, or nervous systems. The following list provides examples of substances that can be toxic:

- Carcinogens, which are substances known to cause cancer in humans or in animals. If cancers have been observed in animals, they could occur in humans. Examples of generally accepted human carcinogens include asbestos, benzene, and vinyl chloride (DIRS 103672-Kamrin 1988, pp. 37 and 38 and Chapter 6).

- Chemicals that controlled studies have shown to cause a harmful or fatal effect. Examples include metals such as cadmium, lead, and mercury; strong acids such as nitric acid and sulfuric acid; some welding fumes; coal dust; sulfur dioxide; and some solvents.

- Some biological materials, including various body fluids and tissues and infectious agents, are toxic.

Even though chemicals might be toxic, many factors influence whether or not a particular substance has a toxic effect on humans. These factors include (1) the amount of the substance with which the person comes in contact, (2) whether the person inhales or ingests a relatively large amount of the substance in a short time (acute exposure) or repeatedly ingests or inhales a relatively small amount over a longer time (chronic exposure), and (3) the period of time over which the exposure occurs.

Scientists determine a substance’s toxic effect (or toxicity) by performing controlled tests on animals. In addition to environmental and physical factors, these tests help establish three other important factors for measuring toxicity—dose-response relationship, threshold concept, and margin of safety. The dose-response relationship relates the percentage of test animals that experience observable toxic effects to the doses administered. After the administration of an initial dose, the dose is increased or decreased until, at the upper end, all animals are affected and, at the lower end, no animals are affected. Thus, there is a threshold concentration below which there is no effect. The margin of safety is an arbitrary separation between the highest concentration or exposure level that produces no adverse effect in a test animal species and the concentration or exposure level designated safe for humans. There is no universal margin of safety. For some chemicals, a small margin of safety is sufficient; others require a larger margin.

Two substances in the rock at Yucca Mountain, crystalline silica and erionite, are of concern as potentially toxic or hazardous materials. Both of these naturally occurring compounds occur in the parent rock at the repository site, and excavation activities could encounter them. The following paragraphs contain additional information on these.

Crystalline Silica

Crystalline silica is a naturally occurring, highly structured form of silica (silicon dioxide, SiO_2). Because it can occur in several different forms, including quartz, cristobalite, and tridymite, it is called a *polymorph*. These three forms occur in the welded tuff parent rock at Yucca Mountain (DIRS 104494-CRWMS M&O 1998, p. 25). Crystalline silica is a known causative agent for *silicosis*, a destructive lung condition caused by deposition of particulate matter in the lungs and characterized by scarring of lung tissue. It is contracted by prolonged exposure to high levels of respirable silica dust or an acute exposure to even higher levels of respirable silica dust (DIRS 103243-EPA 1996, Chapter 8). Accordingly, DOE considers worker inhalation of respirable crystalline silica dust particles to be hazardous to worker health. Current standards for crystalline silica have been established to prevent silicosis in workers.

Cristobalite and tridymite have a lower exposure limit than does quartz. The limits for these forms of silica include the Permissible Exposure Limits established by the Occupational Safety and Health Administration and the Threshold Limit Value defined by the American Conference of Governmental Industrial Hygienists. The Occupational Safety and Health Administration Permissible Exposure Limit for cristobalite or tridymite is 50 micrograms per cubic meter averaged over a 10-hour work shift. The American Conference of Governmental Industrial Hygienists Threshold Limit Value is also 50 micrograms per cubic meter, but it is averaged over an 8-hour work shift (DIRS 103674-NJDHSS 1996, all). Thus, the two limits are essentially the same. In accordance with DOE Order 440.1A (DIRS 138429-DOE 1998, p. 5), the more restrictive value provided by the American Conference of Governmental Industrial Hygienists will be applied. In addition, the National Institute for Occupational Safety and Health has established Immediately-Dangerous-to-Life-and-Health concentration limits at levels of 50,000 and 25,000 micrograms per cubic meter for quartz and cristobalite, respectively (DIRS 147940-NIOSH 1996, p. 2). These limits are based on the maximum airborne concentrations an individual could tolerate for 30 minutes without suffering symptoms that could impair escape from the contaminated area or irreversible acute health effects.

There is also evidence that silica may be a carcinogen. The International Agency for Research on Cancer has classified crystalline silica and cristobalite as a Class I (known) carcinogen (DIRS 100046-IARC 1997, pp. 205 to 210). The National Institute for Occupational Safety and Health considers crystalline silica to be a potential carcinogen, as defined by the Occupational Safety and Health Administration's carcinogen policy (29 CFR Part 1990). The National Institute for Occupational Safety and Health is reviewing data on carcinogenicity, which could result in a revised limit for crystalline silica. The Environmental Protection Agency has noted an increase in cancer risk to humans who have already developed the adverse noncancer effects of silicosis, but the cancer risk to otherwise healthy individuals is not clear (DIRS 103243-EPA 1996, pp. 1 to 5).

Because there are no specific limits for exposure of members of the public to crystalline silica, this analysis used a comparative benchmark of 10 micrograms per cubic meter, based on a cumulative lifetime exposure limit of 1,000 micrograms per (cubic meter multiplied by years). At this level, an Environmental Protection Agency health assessment has stated that there is a less than 1-percent chance of silicosis (DIRS 103243-EPA 1996, Chapter 1, p. 5, and Chapter 7, p. 5). Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter, which was rounded down to 10 micrograms per cubic meter to establish the benchmark. Appendix G, Section G.1 contains additional information on public exposure to crystalline silica.

Samples of the welded tuff parent rock from four boreholes at Yucca Mountain have an average quartz content of 15.7 percent, an average cristobalite content of 16.3 percent, and an average tridymite content of 3.5 percent (DIRS 104494-CRWMS M&O 1998, p. I-1). Worker protection during excavation in the subsurface would be based on the more restrictive Threshold Limit Value for cristobalite. The analysis assumed that the parent rock and dust would have a cristobalite content of 28 percent, which is the higher end of the concentration range reported in DIRS 104523-CRWMS M&O (1999, p. 4-81). Thus, the assumed percentage of cristobalite in dust probably overestimated the airborne cristobalite concentration. Also, studies of both ambient and occupational airborne crystalline silica have shown that most of the airborne crystalline silica is coarse and not respirable (greater than 5 micrometers aerodynamic diameter), and the larger particles deposit rapidly on the surface (DIRS 103243-EPA 1996, p. 3-26).

Erionite

Erionite is a natural fibrous zeolite that occurs in the rock layers below the proposed repository level in the hollows of rhyolitic tuffs and in basalts. It might also occur in rock layers above the repository level but has not been found in those layers. Erionite is a rare tectosilicate zeolite with hexagonal symmetry that forms wool-like fibrous masses (with a maximum fiber length of about 50 microns, which is generally shorter than asbestos fibers) (DIRS 102057-HHS 1994, p. 134).

There are no specific limits for exposure to erionite. Descriptive studies have shown very high mortality from cancer [malignant mesothelioma, mainly of the pleura (a lung membrane)] in the population of three Turkish villages in Cappadocia where erionite is mined. The International Agency for Research on Cancer has indicated that these studies demonstrate the carcinogenicity of erionite to humans. The Agency classifies erionite as a Group 1 (known) carcinogen (DIRS 103278-IARC 1987, all).

Erionite could become a potential hazard during excavation of access tunnels to the lower block and to offset areas for all operating modes or during vertical boring operations necessary to excavate ventilation shafts. DOE does not expect to encounter erionite layers during the vertical boring operations, which would be through rock layers above known erionite layers, or during excavation of access tunnels to the lower block or offset Area 5, where any identified layers of erionite would likely be avoided (DIRS 104532-McKenzie 1998, all). In accordance with the Erionite Protocol (DIRS 104527-YMP 1995, all), a task-specific health and safety plan would be prepared before the start of boring operations to identify this material and prevent worker inhalation exposures from unconfined material.

The Los Alamos National Laboratory is studying the mineralogy and geochemistry of the deposition of erionite under authorization from the DOE Office of Science. Laboratory researchers are applying geochemical modeling so they can understand the factors responsible for the formation of zeolite assemblages in volcanic tuffs. The results of this modeling will be used to predict the distribution of erionite at Yucca Mountain and to assist in the planning of excavation operations so erionite layers are avoided.

F.1.3 EXPOSURE PATHWAYS

Four conditions must exist for there to be a pathway from the source of released radiological or toxic material to a person or population (DIRS 102174-Maheras and Thorne 1993, p. 1):

- A source term: The material released to the environment, including the amount of radioactivity (if any) or mass of material, the physical form (solid, liquid, gas), particle size distribution, and chemical form

- An environmental transport medium: Air, surface water, groundwater, or a food chain

- An exposure route: The method by which a person can come in contact with the material (for example, external exposure from contaminated ground, immersion in contaminated air or internal exposure from inhalation or ingestion of radioactive or toxic material)

- A human receptor: The person or persons potentially exposed; the level of exposure depends on such factors as location, duration of exposure, time spent outdoors, and dietary intake

These four elements define an exposure pathway. For example, one exposure scenario might involve release of contaminated gas from a stack (source term); transport via the airborne pathway (transport medium); external gamma exposure from the passing cloud (exposure route); and an onsite worker (human receptor). Another exposure scenario might involve a volatile organic compound as the source term, release to groundwater as the transport medium, ingestion of contaminated drinking water as the exposure route, and offsite members of the public as the human receptors. No matter which pathway the scenario involves, local factors such as water sources, agriculture, and weather patterns play roles in determining the importance of the pathway when assessing potential human health effects.

Worker exposure to crystalline silica (and possibly erionite) in the subsurface could occur from a rather unique exposure pathway. Mechanical drift excavation, shaft boring, and broken rock management activities could create airborne dust comprising a range of particles sizes. Dust particles smaller than 10 micrometers have little mass and inertia in comparison to their surface area; therefore, these small particles could remain suspended in dry air for long periods. Airborne dust concentrations could increase if the ventilation system recirculated the air or if airflow velocity in the subsurface facilities became high enough to entrain dust previously deposited on drift or equipment surfaces. As tunnel boring machines or road headers break the rock from the working face, water would be applied to wet both the working face and the broken rock to minimize airborne dust levels. Wet or dry dust scrubbers would capture dust that was not suppressed by the water sprays. To prevent air recirculation, which would lead to an increase of airborne dust loads, the fresh air intake and the exhaust air streams would be separated. Finally, the subsurface ventilation system would be designed and operated to control ambient air velocities to minimize dust reentrainment. If these engineering controls did not maintain dust concentrations below the Threshold Limit Value concentration, workers would have to wear respirators until engineering controls established habitable conditions.

F.2 Worker Human Health and Safety Impact Analysis for the Proposed Action Inventory

This section discusses the methodologies and data used to estimate industrial and radiological health and safety impacts to workers that would result from the construction, operation and monitoring, and closure of the Yucca Mountain Repository, as well as the detailed results from the impact calculations. Section F.2.1 describes the methods used to estimate impacts, Section F.2.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources, and Section F.2.3 contains a detailed tabulation of results.

For members of the public, the EIS uses the analysis methods in Appendix G, Section G.2, to estimate radiation dose from radon-222 and crystalline silica released in the subsurface ventilation system exhaust. The radiation dose estimates were converted to estimates of human health impacts using the dose conversion factors discussed in Section F.1.1.5. These impacts are expressed as the probability of a latent cancer fatality for a maximally exposed individual and as the number of latent cancer fatalities among members of the public within about 80 kilometers (50 miles) for the Proposed Action, the retrieval contingency, and the inventory modules. The results are listed in Chapter 4, Section 4.1.7.

Health and safety impacts to workers have been estimated for two worker groups: involved workers and noninvolved workers. Involved workers are craft and operations personnel who would be directly involved in activities related to facility construction and operations, including excavation activities; receipt, handling, packaging, and emplacement of spent nuclear fuel and high-level radioactive waste material; monitoring of conditions and performance of the waste packages; and those directly involved in closure activities. Noninvolved workers are managerial, technical, supervisory, and administrative personnel who would not be directly involved in construction, excavation, operations, monitoring, and closure activities. The analysis did not consider project workers who would not be located at the repository site.

DOE considered two spent nuclear fuel packaging scenarios: (1) receipt in an uncanistered form, and (2) receipt in dual-purpose canisters. These two scenarios bound the impacts from packaging scenarios involving canistered forms.

Health and safety impacts to workers were ascertained to be largest for the uncanistered packaging scenarios in the Draft EIS (see Tables 4-32 and 4-33). Thus, the uncanistered scenarios bound the health and safety impacts to workers.

In this appendix, worker impacts are listed for the uncanistered and dual-purpose canister packaging scenarios. DOE analyzed each scenario under a higher-temperature repository operating mode and a range of lower-temperature operating mode scenarios. The lower-temperature scenarios evaluated conservative and realistic combinations of waste package spacing; commercial spent nuclear fuel aging and blending; use of derated packages; and ventilation operating parameters (method and duration). For the lower-temperature operating mode, DOE limited the analysis for dual-purpose canisters to the scenario with the longest ventilation period without aging. The results show that the combination of uncanistered packaging and lower-temperature operating scenarios would have the highest worker health and safety impacts.

Radiological health impacts to the public are independent of the spent nuclear fuel packaging scenarios. Thus, only one set of radiological health impacts to the public was developed and presented in Chapter 4.

F.2.1 METHODOLOGY FOR CALCULATING OCCUPATIONAL HEALTH AND SAFETY IMPACTS

To estimate the impacts to workers from industrial hazards common to the workplace, values for the full-time equivalent work years for each phase of the project were multiplied by the statistic (occurrence per 10,000 full-time equivalent work years) for the impact being considered. Values for the number of full-time equivalent workers for each phase of the project are listed in Section F.2.2.1. The statistics for industrial impacts for each of the phases are listed in Section F.2.2.2 for involved and noninvolved workers.

Two kinds of radiological health impacts to workers are provided in this EIS. The first is an estimate of the latent cancer fatalities to the worker group involved in a particular project phase. The second is the incremental increase in latent cancer fatality probability attributable to occupational radiation for a maximally exposed individual in the worker population for each project phase.

To calculate the expected number of worker latent cancer fatalities during a phase of the project, the collective dose to the worker group, in person-rem, was multiplied by a standard factor for converting the collective worker dose to projected latent cancer fatalities (see Section F.1.1.5). As discussed in Section F.1.1.5, the value of this factor for radiation workers is 0.0004 excess latent cancer fatality per person-rem of dose.

The collective dose for a particular phase of the operation is calculated as the product of the number of exposed full-time equivalent workers for the project phase (see Section F.2.2.1), the average dose over the exposure period, and the fraction of the working time that a worker is in an environment where there is a source of radiation exposure. Values for exposure rates for both involved and noninvolved workers are presented in Section F.2.2.3 as are the fractional occupancy factors. The calculation of collective dose to subsurface workers from exposure to the radiation emanating from the loaded waste packages is an exception. Collective worker doses from this source of exposure were calculated using the methodology described in Subsurface Engineering File, (DIRS 150941-CRWMS M&O 2000, Appendix G). Estimates of annual exposure rates for subsurface workers from radiation emanating from the waste packages are contained in Table G-5 of that document. Tables G-1 through G-4 of that document contain information that supports the annual exposure rates estimates in Table G-5.

To estimate the incremental increase in the likelihood of death from a latent cancer for the maximally exposed individual, the estimated dose to the maximally exposed worker was multiplied by the factor for converting radiation dose to latent cancers. The factor applied for workers was 0.0004 latent cancer fatality per rem, as discussed above and in Section F.1.1.5. Thus, if a person were to receive a dose of 1 rem, the incremental increase in the probability that person would suffer a latent cancer fatality is 1 in 2,500 or 0.0004.

To estimate the dose for a hypothetical maximally exposed individual, the analysis generally assumed that this individual would be exposed to the radiation fields over the entire duration of a project phase or for 50 years, whichever would be shorter (see Section F.2.2.3). Other sources of exposure while working underground would be ambient radiation coming from the radionuclides in the drift walls and from inhalation of radon-222 and its decay products. The radiation from the waste package is usually the dominant component when these three dose contributors are added. Doses for the maximally exposed subsurface worker were estimated by adding the three dose components because they would occur simultaneously.

F.2.2 DATA SOURCES AND TABULATIONS

F.2.2.1 Work Hours for the Repository Phases

Table F-3 lists the number of workers involved in the various repository phases in terms of full-time equivalent work years. Each full-time equivalent work year represents 2,000 work hours (the number of hours assumed for a normal work year). The sources of the values in the table are indicated by the table references and footnotes. The primary sources of the values are the surface and subsurface engineering files.

In estimating work hours for each of the phases, the duration of the phase is one of the important factors. The durations of the monitoring and closure phases are variable for the different designs analyzed. Values for the phase durations for each of the design cases are presented in the footnotes to Table F-3.

F.2.2.2 Workplace Health and Safety Statistics

The analysis selected health and safety statistics for three impact categories—total recordable cases, lost workday cases, and fatalities. Total recordable cases are occupational injuries or illnesses that result in:

- Fatalities, regardless of the time between the injury and death, or the length of the illness
- Lost workday cases, other than fatalities, that result in lost workdays
- Nonfatal cases without lost workdays that result in transfer to another job, termination of employment, medical treatment (other than first aid), loss of consciousness, or restriction of work or motion

Lost workday cases, which are described above, include cases that result in the loss of more than half a workday. These statistical categories, which have been standardized by the U.S. Department of Labor and the Bureau of Labor Statistics, must be reported annually by employers with 11 or more employees. Table F-4 summarizes the health and safety impact statistics used for this analysis.

Table F-4 cites three sets of statistics that were used to estimate total recordable cases and lost workday cases for workers during activities at the Yucca Mountain site. In addition, there is a fourth statistic related to the occupational fatality projections for the Yucca Mountain site activities. The source of information from which the sets of impact statistics were derived is discussed below. All of the statistics are based on DOE experience for similar types of activities and were derived from the DOE CAIRS

Table F-3. Estimated full-time equivalent worker years for repository phases[a] (page 1 of 2).

				Operating mode			
				Higher-temperature		Lower-temperature	
Phase	Subphase	Period	Worker group	UC[b]	DPC[c]	UC (range)	DPC[d]
Construction	Surface[e]	44 months	Involved	2,800	2,500	2,600 - 2,900	2,500
			Noninvolved	1,100	940	990 - 1,100	940
	Subsurface	5 years	Involved	2,700	2,700	2,700	2,700
			Noninvolved	560	560	560	560
	Solar power generating facility	6 years	Involved	76	76	76	76
			Noninvolved	26	26	26	26
	Aging facilities[f]	16 years	Involved	NA[g]	NA	1,300	NA
			Noninvolved	NA	NA	500	NA
	Construction subtotals			7,300	6,800	7,300 - 8,800	6,800
Operations	Surface handling	First 24 years	Involved	23,000	15,000	23,000 - 24,000	15,000
			Noninvolved	8,200	9,300	8,200	9,300
		Last 26 years (aging only)[h]	Involved	NA	NA	13,000	NA
			Noninvolved	NA	NA	4,400	NA
	Subsurface emplacement	First 24 years[i]	Involved	1,800	1,800	1,800 - 2,500	1,800
			Noninvolved	380	380	380 - 530	380
		Last 26 years (aging only)[j]	Involved	NA	NA	1,900	NA
			Noninvolved	NA	NA	420	NA
	Subsurface development	22 years[k]	Involved	6,200	6,200	6,600 - 7,500	6,600
			Noninvolved	2,000	2,000	2200	2,200
	Operations subtotals			4,2000	34,000	42,000 - 63,000	35,000
Monitoring	Surface facility decontamination	3 years	Involved	2,700	2,000	2,200 - 2,700	2,000
			Noninvolved	690	610	610 - 690	610
	Surface	Variable[l]	Involved	2,600	2,600	3,400 - 10,000	10,000
			Noninvolved	0	0	0	0
	Subsurface	Variable[m]	Involved	5,200	5,200	6,800 - 21,000	21,000
			Noninvolved	990	990	1,300 - 3,900	3,900
	Solar panel maintenance	Variable[n]	Involved	180	180	270 - 580	580
	Solar panel replacement	Every 20 years[o]	Involved	36	36	63 - 140	140
	Monitoring subtotals			12,000	12,000	15,000 - 39,000	38,000
Closure	Surface facilities	6 years	Involved	2,900	2,500	2,900	2,500
			Noninvolved	1,100	950	1,100	950
	Subsurface	Variable[p]	Involved	2,400	2,400	2,600 - 4,000	2,600
			Noninvolved	450	450	500 - 770	500
	Solar power generating facility	6 years	Involved	62	62	62	62
			Noninvolved	24	24	24	24
	Closure subtotals			6,900	6,400	7,100 - 8,800	6,700
Totals				***68,000***	***59,000***	***77,000 - 110,000***	***87,000***

Table F-3. Estimated full-time equivalent worker years for repository phases[a] (page 2 of 2).

a. Sources: Derived from DIRS 152010-CRWMS M&O (2000, all); DIRS 150941-CRWMS M&O (2000, all); DIRS 155516-Williams (2001, all); DIRS 155515-Williams (2001, all); DIRS 153882-Griffith (2001, all); DIRS 154758-Lane (2000, all); DIRS 153958-Morton (2000, all).

b. UC = uncanistered packaging scenario.

c. DPC = dual-purpose canister packaging scenario.

d. Values are for the lower-temperature long-term ventilation scenario without aging, which would require the greatest number of worker-years for the dual-purpose canister packaging scenario among the lower-temperature scenarios.

e. For the aging and derated waste package scenarios, the analysis applied the ratios of total buildings size between the higher-temperature scenario and the aging and derated waste package scenarios to calculate worker-year values for surface construction in those scenarios. Those ratios are 0.94 for aging scenarios and 1.04 for the derated waste package scenario.

f. For aging scenarios, the analysis assumed that the worker-year values for construction of the surface aging facility would be four-sevenths of those for a 70,000-MTHM retrieval facility. The analysis further assumed that initial construction of one-eighth of the aging pads would occur over 2 years from 2008 to 2010, and that the remaining aging pads would be constructed over the next 14 years, as needed.

g. NA = not applicable.

h. For the last 26 years of surface handling for the aging scenarios, the scale of waste handling operations in the surface facilities would decrease because no more waste would be received. The analysis assumed that the annual number of workers would be one-half of that for the first 24 years.

i. For the derated waste package scenario, the analysis assumed that the ratio of the number of derated waste packages to the number of higher-temperature mode full-size packages (15,600 : 11,300, or 1.38) would apply to the number of involved and noninvolved workers emplacing those waste packages.

j. For the last 26 years of emplacement for the aging scenarios, while the emplacement rate would be substantially reduced, the analysis conservatively assumed no reduction in annual staffing levels.

k. Though the subsurface development period would remain 22 years, annual staffing would be increased to meet the additional excavation demands for the lower-temperature repository operating mode. For the aging scenarios, the development period could be longer, but the number of worker-years would be the same because the amount of excavation would be the same with or without aging.

l. Surface monitoring periods would extend from the end of surface decontamination to the beginning of closure: higher-temperature, 73 years; lower-temperature with long-term ventilation without aging, 297 years; lower-temperature with long-term ventilation with aging, 271 years; lower-temperature with maximum spacing without aging, 122 years; lower-temperature with maximum spacing with aging, 96 years. For scenarios with aging, monitoring and emplacement activities could overlap for part of the last 26 years of the 50-year aging emplacement period.

m. Subsurface monitoring periods would extend from the end of emplacement to the beginning of closure: higher-temperature, 76 years; lower-temperature with long-term ventilation without aging, 300 years; lower-temperature with long-term ventilation with aging, 274 years; lower-temperature with maximum spacing without aging, 125 years; lower-temperature with maximum spacing with aging, 99 years. For scenarios with aging, monitoring and emplacement activities could overlap for part of the last 26 years of the 50-year aging emplacement period.

n. Solar power facility operations would extend from the beginning of emplacement to the end of monitoring: higher-temperature, 100 years; lower-temperature with long-term ventilation, 324 years; lower-temperature with maximum spacing, 149 years.

o. Solar panels would require replacement every 20 years, involving about 9 worker-years per replacement (6 workers for 3 months for each of 6 arrays). Panels would be replaced 4 times for the 100-year higher-temperature mode operating-period, 16 times during the 324-year lower-temperature with long-term ventilation operating-period, and 7 times during the 149-year lower-temperature with maximum spacing operating-period.

p. Subsurface closure periods: Higher-temperature operating mode, 10 years; lower-temperature operating mode with long-term ventilation with or without aging and with natural ventilation, 11 years; lower-temperature operating mode with long-term ventilation with derated waste packages, 12 years; lower-temperature operating mode with maximum spacing, 17 years.

Table F-4. Health and safety statistics for estimating industrial safety impacts common to the workplace.

Phase	Total recordable cases incidents per 100 FTEs[a]		Lost workday cases per 100 FTEs		Fatalities per 100,000 FTEs (involved and noninvolved)[b]	Data set for TRCs and LWCs[c,d]
	Involved	Noninvolved	Involved	Noninvolved		
Construction						
Surface	6.1	3.3	2.9	1.6	2.9	(1)
Subsurface	6.1	3.3	2.9	1.6	2.9	(1)
Operation and Monitoring						
Operation period						
Surface	3	3.3	1.2	1.6	2.9	(3)
Subsurface - emplacement	3	3.3	1.2	1.6	2.9	(3)
Subsurface - drift development	6.8	1.1	4.8	0.7	2.9	(2)
Monitoring period						
Surface	3	3.3	1.2	1.6	2.9	(3)
Subsurface	3	3.3	1.2	1.6	2.9	(3)
Closure						
Surface	6.1	3.3	2.9	1.6	2.9	(1)
Subsurface	6.1	3.3	2.9	1.6	2.9	(1)

a. FTEs = full-time equivalent worker years.
b. See the discussion about Data Set 4 for source of fatality statistic for normal industrial activities.
c. TRCs = total recordable cases; LWCs = lost workday cases.
d. See text below for source of data in Data Sets 1, 2, and 3.

(Computerized Accident/Incident Reporting and Recordkeeping System) database (DIRS 147938-DOE 1999, all).

Data Set 1, Construction and Construction-Like Activities

This set of statistics from the DOE CAIRS database was applied to construction or construction-like activities. Specifically, it was used for both surface and subsurface workers during the construction phase and the closure phase (closure phase activities were deemed to be construction-like activities). The statistics were based on a 6.75-year period (1992 through the third quarter of 1998).

For involved workers the impact statistic numbers were derived from the totals for all of the DOE construction activities over the period. For noninvolved workers, the values were derived from the combined government and services contractor noninvolved groups for the same period. The noninvolved worker statistic, then, is representative of impacts for oversight personnel who would not be involved in the actual operation of equipment or resources. The basic statistics derived from the CAIRS database for each of the groups include:

- Involved worker total recordable cases: 764 recordable cases for approximately 12,400 full-time equivalent work years

- Involved worker lost workday cases: 367 lost workday cases for approximately 12,400 full-time equivalent work years

- Noninvolved worker total recordable cases: 1,333 recordable cases for approximately 40,600 full-time equivalent work years

- Noninvolved worker lost workday cases: 657 lost workday cases for approximately 40,600 full-time equivalent work years

Data Set 2, Excavation Activities

This set of statistics was derived from experience at the Yucca Mountain Project over a 30-month period (fourth quarter of 1994 though the first quarter of 1997). DOE selected this period because it coincided with the exploratory tunnel boring machine operations at Yucca Mountain, reflecting a high level of worker activity during ongoing excavation activities. This statistic was applied for the Yucca Mountain Project subsurface development period, which principally involves drift development activities. The Yucca Mountain Project experience from which the statistic is derived is presented in Table F-5. DIRS 104543-Stewart (1998, all) contains the Yucca Mountain statistics, which were derived from the CAIRS database (DIRS 147938-DOE 1999, all).

Table F-5. Yucca Mountain Project worker industrial safety loss experience.[a]

Factor	Value[b]	Basis
TRCs[c] per 100 FTEs[d]		
Involved worker	6.8	56 TRCs for 825 construction FTEs
Noninvolved worker	1.1	23 TRCs for 2,015 nonconstruction FTEs
LWCs[e] per 100 FTEs		
Involved worker	4.8	40 LWCs for 825 construction FTEs
Noninvolved worker	0.7	14 LWCs for 2,015 nonconstruction FTEs
Fatality rate occurrence per 100,000 FTEs		
Involved worker	0.0	No fatalities for 825 construction FTEs
Noninvolved worker	0.0	No fatalities for 2,015 nonconstruction FTEs

a. Fourth quarter 1994 through first quarter 1997.
b. Source: Adapted from the CAIRS database (DIRS 147938-DOE 1999, all) by DIRS 104543-Stewart (1998, all) for the fourth quarter of 1994 through the first quarter of 1997.
c. TRCs = total recordable cases.
d. FTEs = full-time equivalent worker years.
e. LWCs = lost workday cases.

Data Set 3, Activities Involving Work in a Radiological Environment

This set of statistics is from the DOE CAIRS database (DIRS 147938-DOE 1999, all). In arriving at the statistics listed in Table F-4, information from the Savannah River Site, the Hanford Site, and the Idaho National Engineering and Environmental Laboratory was averaged individually for the 6.5 years from 1992 through the second quarter of 1998. The averages were then combined to produce an overall average. The reason these three sites were selected as the basis for this set of statistics is that the DOE Savannah River, Hanford, and Idaho National Engineering and Environmental Laboratory sites currently conduct most of the operations in the DOE complex involving handling, sorting, storing, and inspecting spent nuclear fuel and high-level radioactive waste materials, as well as similar activities for low-level radioactive waste materials. The Yucca Mountain Repository phases for which this set of statistics was applied included the receipt, handling, and packaging of spent nuclear fuel and high-level radioactive waste in the surface facilities; subsurface emplacement activities; and surface and subsurface monitoring activities, including decontamination of the surface facilities. These activities involve handling, storing, and inspecting spent nuclear fuel and high-level radioactive waste. The worker activities at the Yucca Mountain site are expected to be similar to those cited above for the other sites in the DOE complex.

The basic statistics for the involved and noninvolved workers include:

- Involved worker total recordable cases: 1,246 for about 41,600 full-time equivalent work years
- Involved worker lost workday cases: 538 for about 41,600 full-time equivalent work years
- Noninvolved worker total recordable cases: 1,333 for about 40,600 full-time equivalent work years
- Noninvolved worker lost workday cases: 657 for about 40,600 full-time equivalent work years

Data Set 4, Statistics for Worker Fatalities from Industrial Hazards

There have been no reported fatalities as a result of workplace activities for the Yucca Mountain project. Similarly, there are no fatalities listed in the Mine Safety and Health Administration database for stone mining workers (DIRS 147939-MSHA n.d., all). Because fatalities in industrial operations sometimes occur, the more extensive overall DOE database was used to estimate a fatality rate for the activities at the Yucca Mountain site. Statistics for the DOE facility complex for the 10 years between 1988 and 1997 were used (DIRS 147938-DOE 1999, all). These fatality statistics are for both government and contractor personnel working in the DOE complex who were involved in the operation of equipment and resources (involved workers). The activities in the DOE complex covered by this statistic were governed by safety and administrative controls (under the DOE Order System) that are similar to the safety and administrative controls that would be applied for Yucca Mountain Repository work. These fatality statistics were also applied to the noninvolved worker population because they are the most inclusive statistics in the CAIRS database. However, the statistics probably are conservatively high for the noninvolved worker group.

F.2.2.3 Estimates of Radiological Exposures

DOE considered the following potential sources of radiation exposure for assessing radiological health impacts to workers:

- Inhalation of gaseous radon-222 and its decay products. Subsurface workers could inhale the radon-222 present in the air in the repository drifts. Workers on the surface could inhale radon-222 released to the environment in the exhaust air from the subsurface ventilation system.

- External exposure of surface workers to radioactive gaseous fission products that could be released during handling and packaging of spent nuclear fuel with failed cladding for emplacement in the repository. Such impacts would be of most concern for the uncanistered packaging scenario.

- Direct external exposure of workers in the repository drifts as a result of naturally occurring radionuclides in the walls of the drifts (primarily potassium-40 and radionuclides of the naturally occurring uranium and thorium decay series).

- External exposure of workers to direct radiation emanating from the waste packages containing spent nuclear fuel and high-level radioactive waste either during handling and packaging (surface facility workers) or after it is placed within the waste package (largely subsurface workers).

Section F.1.1.6 describes the approach taken to estimate exposures to workers as a result of inhalation of gaseous radon-222 released from the drift walls to the subsurface atmosphere. For radon exposures to subsurface workers, the analysis assumed a subsurface occupancy factor of 1.0 for involved workers, an occupancy factor of 0.6 for noninvolved workers for construction and drift development activities, and an occupancy factor of 0.4 for noninvolved workers for emplacement, monitoring, and closure (DIRS 104533-Rasmussen 1998, all; DIRS 104536-Rasmussen 1999, all; DIRS 104528-Jessen 1999, all).

As discussed in Section F.1.1.6, the average concentration of radon-222 and its progeny in the subsurface atmosphere varies with factors such as location within the repository (main drifts or emplacement drifts), whether or not concrete lining is in place in the main drifts, the subsurface ventilation rate, and the repository volume. Table F-2 lists estimated doses to subsurface workers from inhalation of radon-222 and its progeny.

Appendix G, Section G.2.3.2, describes the approach taken to estimate source terms and associated doses to workers from the potential release of gaseous fission products from spent nuclear fuel with failed cladding.

Subsurface workers would also be exposed to background gamma radiation from naturally occurring radionuclides in the subsurface rock (largely from the thorium and uranium-238 decay series radionuclides and from potassium-40, all in the rock). DOE has based its projection of worker external gamma dose rates on the data obtained during Exploratory Studies Facility operations (Sections F.1.1.6 and G.2.3.1). The collective ambient radiation exposures for subsurface workers were calculated assuming occupancy factors cited in the previous paragraph for subsurface workers for emplacement and monitoring activities (DIRS 104533-Rasmussen 1998, all; DIRS 104536-Rasmussen 1999, all; DIRS 104528-Jessen 1999, all). The average exposure level, as listed in Table F-7, is 50 millirem per year.

Estimates of subsurface worker exposure as a result of radiation emanating from the waste packages are developed in subsurface facility engineering file (DIRS 150941-CRWMS M&O 2000, Appendix G). Specifically, Tables G-1, G-2, and G-3 of this engineering file list estimates of exposures from the waste packages in the various repository regions. Table G-5 of this engineering file lists manpower distributions for involved workers who would be exposed to radiation emanating from the waste packages. Tables G-4 and G-6 of the engineering file list estimates of annual exposures from radiation emanating from the waste packages. Table F-6 below summarizes the estimates of subsurface worker exposures from radiation emanating from the waste packages during the operation and monitoring and closure phases.

Table F-6. Estimated annual subsurface worker exposures to radiation emanating from waste packages.[a]

	Operating mode				
		Lower-temperature			
Operations phase	Higher-temperature	Long-term ventilation	Long-term ventilation (natural ventilation after 50 years)	Derated waste packages	Maximum spacing
Emplacement					
First 24 years (person-rem per year)[b]	6.0	6.0	6.0	8.3	6.0
Latter period of emplacement for aging cases (person-rem per year)[c]	N/A[d]	6.0	N/A	N/A	6.0
Monitoring (person-rem per year)[e]	3.7	3.7	3.7	3.7	3.7
Monitoring for natural ventilation period (person-rem per year)[f]	N/A	N/A	1.07	N/A	N/A
Closure (overall exposure in person-rem)[g]	270	300	300	330	460

a. Numbers are rounded to two significant figures.
b. Sources: Tables G-4 and G-6 of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).
c. For aging cases, it is assumed that 90 full-time equivalent workers are retained for emplacement. Annual exposure levels are assumed to be the same as for the first 24 years.
d. N/A = not applicable.
e. Source: Table G-6 of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).
f. It is assumed that the annual exposure from radiation emanating from the waste packages is reduced by the ratio of full-time equivalent workers for the forced ventilation period to those for the 250-year natural ventilation period. See Tables I-18 and I-18a for long-term ventilation in letter update to the Subsurface Engineering File (DIRS 155515-Williams 2001, all).
g. Values derived from Appendixes G and H of the Subsurface Engineering File (DIRS 150941-CRWMS M&O 2000).

Table F-7 summarizes the exposure values used in this appendix for estimating overall worker exposures. Values are presented for both the uncanistered packaging scenario and for the dual-purpose canister packaging scenario where appropriate. The table also lists the references or sources from which the data were obtained.

Table F-8 contains estimates of overall annual radiation exposure to surface workers during the waste package handling and packaging operations in preparation for emplacement. The values for the design case with blending are derived from the values listed in Table 6-2 of the Surface Engineering File (DIRS 152010-CRWMS M&O 2000). The estimates for design cases with surface aging prior to emplacement and for the derated waste package design cases were derived from the supplemental information provided in the surface facilities EIS letter report (DIRS 155516-Williams 2001, Section 3.1).

Table F-7. Radiological exposure data used to calculate worker radiological health impacts[a] (page 1 of 2).

Phase and worker group	Exposure source[b]	Occupancy factor[c]	Annual dose (millirem, except where noted)	Annual full-time equivalent workers[d]: Derated waste package	Annual full-time equivalent workers[d]: UC[e]	Annual full-time equivalent workers[d]: DPC[f]	Data source[g]
Construction							
Surface							
Involved	Radon-222 inhalation	1.0	Small relative to subsurface worker exposures				h
Noninvolved	Radon-222 inhalation	1.0	Small relative to subsurface worker exposures				h
Subsurface							
Involved	Drift ambient	1.0	50				g(1)
	Radon-222 inhalation	1.0	200				Table F-2, g(2)
Noninvolved	Drift ambient	0.6	50				g(1), g(5), g(6)
	Radon-222 inhalation	0.6	60				Table F-2, g(5), g(6)
Surface handling and loading operations							
Involved	Receipt, handling and packaging of spent nuclear fuel and high-level radioactive waste	1.0	Table F-8				See Table F-8
Noninvolved	Receipt, handling and packaging of spent nuclear fuel and high-level radioactive waste	1.0	0				g(7)
Surface							
Involved only	Radon-222 inhalation	1.0	Small relative to subsurface workers				i
Subsurface emplacement							
Involved	Waste package	1.0	Table F-6				Table F-6
	Drift ambient	1.0	50				g(1)
	Radon-222	1.0	120				Table F-2
Noninvolved	Waste package	0.04	200				g(2)
	Drift ambient	0.4	50				g(1), g(5), g(6)
	Radon-222 inhalation	0.4	20				Table F-2, g(5), g(6)
Subsurface drift development							
Involved	Drift ambient	1.0	50				g(1)
	Radon-222 inhalation	1.0	200				Table F-2
Noninvolved	Drift ambient	0.6	50				g(1), g(5), g(6)
	Radon-222 inhalation	0.6	60				Table F-2, g(5), g(6)
Monitoring							
Surface decontamination (postemplacement)							
Involved		1.0	25	2,190	2,663	1,993	g(4), g(8)
Noninvolved		1.0	0	605	689	583	
Subsurface							
Involved	Waste package	1.0	Table F-6				Table F-6
	Drift ambient	1.0	50				g(1)
	Radon-222 inhalation	1.0	100				Table F-2, g(5), g(6)
Noninvolved	Waste package	0.04	200				g(2)
	Drift ambient	0.4	50				g(1), g(5), g(6)
	Radon-222 inhalation	0.4	20				Table F-2, g(5), g(6)
Surface monitoring							
Involved only	Radon-222 inhalation	1.0	Small relative to subsurface workers				j

Table F-7. Radiological exposure data used to calculate worker radiological health impacts[a] (page 2 of 2).

Phase and worker group	Exposure source[b]	Occupancy factor[c]	Annual dose (millirem, except where noted)	Annual full-time equivalent workers[d]: Derated waste package	UC[e]	DPC[f]	Data source[g]
Closure							
Surface							
Involved		1.0	Small relative to subsurface worker exposures				k
Noninvolved		1.0	Small relative to subsurface worker exposures				k
Subsurface							
Involved	Waste package	1.0	Table F-6				Table F-6
	Drift ambient	1.0	50				g(1)
	Radon-222 inhalation	1.0	20				Table F-2
Noninvolved	Waste package	0.04	200				g(2)
	Drift ambient	0.4	50				g(1), g(5), g(6)
	Radon-22 inhalation	0.4	20				Table F-2, g(5), g(6)

a. Numbers are rounded to two significant figures.
b. Exposure sources include radiation from spent nuclear fuel and high-level radioactive waste packages to surface and subsurface workers, the ambient exposure to subsurface workers from naturally occurring radiation in the drift walls, and internal exposures from inhalation of radon-222 and its decay products in the drift atmosphere by subsurface workers.
c. Fraction of 8-hour workday that workers are exposed.
d. Number of annual full-time equivalent workers for surface facility activities when the number of workers in each exposure category would vary with packaging scenario.
e. UC = uncanistered packaging scenario.
f. DPC = dual-purpose canister packaging scenario.
g. Sources:
  (1) Section F.1.1.6.
  (2) DIRS 104533-Rasmussen (1998, all).
  (3) DIRS 150941-CRWMS M&O (2000 Subsurface Facility Engineering File, Table G-6).
  (4) DIRS 152010-CRWMS M&O (2000 Surface Engineering File, Table 6-4).
  (5) DIRS 104536-Rasmussen (1999, all).
  (6) DIRS 104528-Jessen (1999, all).
  (7) DIRS 152010-CRWMS M&O (2000 Surface Engineering File, Table 6-2).
  (8) DIRS 155516-Williams (2001, Section 3.1).
h. Comparison of information in Chapter 4, Table 4-2 (surface workers) and Table F-11 (subsurface workers).
i. Comparison of information in Chapter 4, Table 4-5 (surface workers) and Tables F-20 and F-21 (subsurface workers).
j. Comparison of information in Chapter 4, Table 4-7 (surface workers) and Table F-30 (subsurface workers).
k. Comparison of information in Chapter 4, Table 4-5 (surface workers) and Table F-37 (subsurface workers).

Table F-8. Estimates of annual exposures (person-rem per year) for surface facility workers during handling and packaging of waste material for emplacement.[a]

Period	Packaging scenario	Blending	Aging via surface storage	Derated waste packages
First 24 years	Uncanistered	230[b]	240[c]	240[c]
	Dual-purpose canister	120[b]	NA[d]	NA
Latter period for aging cases	NA	NA	160[e]	NA

a. Numbers are rounded to two significant figures.
b. DIRS 152010-CRWMS M&O (2000, Table 6-2).
c. DIRS 155516-Williams (2001, Section 3.1); values adjusted upward by a ratio of 119/117 for the uncanistered case.
d. NA = not applicable to the operation listed.
e. For surface storage cases (aging), it is assumed that the annual average cumulative exposure to surface facility workers is two-thirds that for the first 24 years based on handling of about 2,000 MTHM per year rather than 3,000 MTHM per year.

F.2.3 COMPILATION OF DETAILED RESULTS FOR OCCUPATIONAL HEALTH AND SAFETY IMPACTS

F.2.3.1 Occupational Health and Safety Impacts During the Construction Phase

F.2.3.1.1 *Industrial Hazards to Workers*

Tables F-9 and F-10 list health and safety impacts from industrial hazards to surface and subsurface workers, respectively, for construction activities.

Table F-9. Industrial hazard health and safety impacts to surface facility workers during construction phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	180	160	180 - 210	160
Lost workday cases	84	74	84 - 99	74
Fatalities	0.084	0.074	0.084 - 0.099	0.074
Noninvolved				
Total recordable cases of injury and illness	36	32	36 - 43	32
Lost workday cases	18	16	18 - 21	16
Fatalities	0.032	0.028	0.032 - 0.038	0.028
All workers (totals)[e]				
Total recordable cases of injury and illness	220	190	220 - 250	190
Lost workday cases	100	90	100 - 120	90
Fatalities	0.12	0.10	0.12 - 0.14	0.10

a. Source: Impact rates from Table F-4; includes all construction activities.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-10. Industrial hazard health and safety impacts to subsurface facility workers during construction phase.[a,b]

Worker group	All operating modes
Involved	
Total recordable cases of injury and illness	170
Lost workday cases	79
Fatalities	0.079
Noninvolved	
Total recordable cases of injury and illness	18
Lost workday cases	9
Fatalities	0.016
All workers (totals)[c]	
Total recordable cases of injury and illness	190
Lost workday cases	88
Fatalities	0.095

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. Totals might differ from sums of values due to rounding.

F.2.3.1.2 *Radiological Health Impacts to Workers*

Table F-11 lists subsurface worker health impacts from inhalation of radon-222 in the subsurface atmosphere and from ambient radiation exposure from radionuclides in the rock of the drift walls. The radiological health impacts to surface workers from inhalation of radon-222 would be small in comparison to those for subsurface workers; therefore, they were not tabulated in this appendix (see Table F-7, Footnotes h to k for sources of comparison).

Table F-11. Radiological health impacts to subsurface facility workers from radon exposure and ambient radiation during construction phase.[a,b]

Worker group	Radon	Ambient radiation	Total[c]
Involved worker			
Dose to maximally exposed worker (millirem)	1,000	250	1,300
Probability of latent cancer fatality	0.0004	0.0001	0.00052
Collective dose (person-rem)	550	140	680
Number of latent cancer fatalities	0.22	0.056	0.27
Noninvolved worker			
Dose to maximally exposed worker (millirem)	180	150	330
Probability of latent cancer fatality	0.000072	0.00006	0.00013
Collective dose (person-rem)	20	17	37
Number of latent cancer fatalities	0.008	0.0068	0.015
All workers (totals)[c]			
Dose to maximally exposed worker (millirem)	1,180	400	1,630
Probability of latent cancer fatality	0.000472	0.00016	0.00065
Collective dose (person-rem)	570	160	720
Number of latent cancer fatalities	0.23	0.064	0.29

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. Totals might differ from sums of values due to rounding.

F.2.3.1.3 *Summary of Impacts for Construction Phase*

Table F-12 summarizes the estimated health and safety impacts from industrial hazards. The radiological health impacts were summarized in Table F-11.

Table F-12. Summary of estimated impacts to workers from industrial hazards during construction phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	340	320	340 - 370	320
Lost workday cases	160	150	160 - 180	150
Fatalities	0.16	0.15	0.16 - 0.18	0.15
Noninvolved				
Total recordable cases of injury and illness	55	50	55 - 61	50
Lost workday cases	27	24	27 - 30	24
Fatalities	0.048	0.044	0.048 - 0.054	0.044
All workers (total)[e]				
Total recordable cases of injury and illness	400	370	400 - 430	370
Lost workday cases	190	170	190 - 210	170
Fatalities	0.21	0.19	0.21 - 0.23	0.19

a. Values are sums of values in Tables F-9 and F-10.
b. Includes all construction activities.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.2 Occupational Health and Safety Impacts During the Operations Period

F.2.3.2.1 *Industrial Safety Hazards to Workers*

Table F-13 lists the estimated impacts from industrial hazards for the surface facility workers during waste receipt and packaging, surface storage of waste, retrieval of the waste from surface storage, and preparation of the stored waste for emplacement. Table F-14 lists the estimated impacts from industrial hazards to subsurface workers involved in drift development activities, and Table F-15 lists estimated impacts from industrial hazards to subsurface workers involved in emplacement activities.

Table F-13. Industrial hazard health and safety impacts to surface facility workers involved in waste receipt and packaging activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	690	440	690 - 1,100	440
Lost workday cases	280	180	280 - 430	180
Fatalities	0.67	0.43	0.67 - 1.1	0.43
Noninvolved				
Total recordable cases of injury and illness	270	310	270 - 420	310
Lost workday cases	130	150	130 - 200	150
Fatalities	0.24	0.27	0.24 - 0.37	0.27
All workers (total)[e]				
Total recordable cases of injury and illness	960	750	960 - 1500	750
Lost workday cases	410	330	410 - 630	330
Fatalities	0.91	0.7	0.91 - 1.5	0.7

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-14. Industrial hazard health and safety impacts to subsurface workers involved in drift development activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	420	420	450 - 510	450
Lost workday cases	300	300	320 - 360	320
Fatalities	0.18	0.18	0.19 - 0.22	0.19
Noninvolved				
Total recordable cases of injury and illness	22	22	24	24
Lost workday cases	14	14	15	15
Fatalities	0.058	0.058	0.064	0.064
All workers (total)[e]				
Total recordable cases of injury and illness	440	440	470 - 530	470
Lost workday cases	310	310	340 - 380	340
Fatalities	0.24	0.24	0.25 - 0.28	0.25

a. Source: Calculated using impact rates from Tables F-4 and F-5.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-15. Industrial health hazard and safety impacts to subsurface facility workers involved in emplacement activities.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	53	53	53 - 110	53
Lost workday cases	21	21	21 - 44	21
Fatalities	0.052	0.052	0.052 - 0.11	0.052
Noninvolved				
Total recordable cases of injury and illness	13	13	13 - 26	13
Lost workday cases	6.1	6.1	6.1 - 13	6.1
Fatalities	0.011	0.011	0.011 - 0.023	0.011
All workers (total)[e]				
Total recordable cases of injury and illness	66	66	66 - 140	66
Lost workday cases	27	27	27 - 57	27
Fatalities	0.063	0.063	0.063 - 0.13	0.063

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.2.2 *Radiological Health Impacts to Workers*

Radiological health impacts to surface and subsurface workers are listed in Tables F-16 through F-21.

- Table F-16 summarizes the radiological health impacts to surface facility workers involved in handling and packaging of incoming waste materials, surface storage of materials, and recovery and repackaging of the stored materials.

- Table F-17 lists radiological health impacts from radiation emanating from waste packages to subsurface workers involved in emplacement activities.

- Table F-18 lists radiological health impacts from ambient radiation emanating from drift walls to subsurface facility workers involved in emplacement activities.

- Table F-19 lists radiological health impacts from ambient radiation emanating from the drift walls to subsurface workers involved in drift development activities.

- Table F-20 lists radiological health impacts from inhalation of radon-222 and its decay products to subsurface workers involved in emplacement activities.

- Table F-21 lists radiological health impacts from inhalation of radon-222 and its decay products to subsurface workers involved in drift development activities.

Table F-16. Estimated exposures and radiological health impacts to surface facility workers during the operations period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	9,600	9,600	9,600 - 18,000	9,600
Probability of latent cancer fatality	0.0038	0.0038	0.0038 - 0.0072	0.0038
Collective dose (person-rem)	5,500	2,800	5,500 - 9,100	2,800
Number of latent cancer fatalities	2.2	1.1	2.2 - 3.6	1.1
Noninvolved worker				
Dose to maximally exposed worker (millirem)	0	0	0	0
Probability of latent cancer fatality	0	0	0	0
Collective dose (person-rem)	0	0	0	0
Number of latent cancer fatalities	0	0	0	0
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	9,600	9,600	9,600 - 18,000	9,600
Probability of latent cancer fatality	0.0038	0.0038	0.0038 - 0.0072	0.0038
Collective dose (person-rem)	5,500	2,800	5,500 - 9,100	2,800
Number of latent cancer fatalities	2.2	1.1	2.2 - 3.6	1.1

a. Source: Exposure values from Table F-10.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-17. Radiological health impacts from radiation emanating from waste packages to subsurface facility workers involved in emplacement activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)[e]	11,000	11,000	11,000 - 22,000	11,000
Probability of latent cancer fatality	0.0044	0.0044	0.0044 - 0.0088	0.0044
Collective dose (person-rem)	140	140	140 - 290	140
Number of latent cancer fatalities	0.056	0.056	0.056 - 0.12	0.056
Noninvolved worker				
Dose to maximally exposed worker (millirem)	190	190	190 - 400	190
Probability of latent cancer fatality	0.000076	0.000076	0.000076 - 0.00016	0.000076
Collective dose (person-rem)	3.1	3.1	3.1 - 6.4	3.1
Number of latent cancer fatalities	0.0012	0.0012	0.0012 - 0.0026	0.0012
All workers (totals)[f]				
Dose to maximally exposed worker (millirem)	11,190	11,190	11,190 - 22,400	11,190
Probability of latent cancer fatality	0.004476	0.004476	0.004476 - 0.00896	0.004476
Collective dose (person-rem)	140	140	140 - 300	140
Number of latent cancer fatalities	0.056	0.056	0.056 - 0.12	0.056

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Maximally exposed individual, (DIRS 150941-CRWMS M&O 2000, Table G-4).
f. Totals might differ from sums of values due to rounding.

Table F-18. Radiological health impacts from ambient radiation to subsurface facility workers involved in emplacement activities.[a,b]

Worker group	Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC range	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	1,200	1,200	1,200 - 2,500	1,200
Probability of latent cancer fatality	0.00048	0.00048	0.00048 - 0.001	0.00048
Collective dose (person-rem)	89	89	89 - 190	89
Number of latent cancer fatalities	0.036	0.036	0.036 - 0.076	0.036
Noninvolved worker				
Dose to maximally exposed worker (millirem)	480	480	480 - 1,000	480
Probability of latent cancer fatality	0.00019	0.00019	0.00019 - 0.0004	0.00019
Collective dose (person-rem)	7.7	7.7	7.7 - 16	7.7
Number of latent cancer fatalities	0.0031	0.0031	0.0031 - 0.006	0.0031
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	1,680	1,680	1,680 - 3,500	1,680
Probability of latent cancer fatality	0.00067	0.00067	0.00067 - 0.0014	0.00067
Collective dose (person-rem)	97	97	97 - 210	97
Number of latent cancer fatalities	0.039	0.039	0.039 - 0.08	0.039

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-19. Radiological impacts from ambient radiation to subsurface workers involved in development activities.[a,b]

Worker group	Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC range	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	1,100	1,100	1,100	1,100
Probability of latent cancer fatality	0.00044	0.00044	0.0004	0.00044
Collective dose (person-rem)	310	310	330 - 370	330
Number of latent cancer fatalities	0.12	0.12	0.13 - 0.15	0.13
Noninvolved worker				
Dose to maximally exposed worker (millirem)	660	660	660	660
Probability of latent cancer fatality	0.00026	0.00026	0.00026	0.00026
Collective dose (person-rem)	60	60	66	66
Number of latent cancer fatalities	0.024	0.024	0.026	0.026
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	1,760	1,760	1,760	1,760
Probability of latent cancer fatality	0.0007	0.0007	0.00066	0.0007
Collective dose (person-rem)	370	370	400 - 440	400
Number of latent cancer fatalities	0.15	0.15	0.16 - 0.18	0.16

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-20. Radiological health impacts from airborne radon-222 to subsurface facility workers involved in emplacement activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	2,900	2,900	2,900 - 6,000	2,900
Probability of latent cancer fatality	0.0012	0.0012	0.0012 - 0.0024	0.0012
Collective dose (person-rem)	210	210	210 - 440	210
Number of latent cancer fatalities	0.084	0.084	0.084 - 0.18	0.084
Noninvolved worker				
Dose to maximally exposed worker (millirem)	190	190	190 - 400	190
Probability of latent cancer fatality	0.000076	0.000076	0.000076 - 0.00016	0.000076
Collective dose (person-rem)	3.1	3.1	3.1 - 6.4	3.1
Number of latent cancer fatalities	0.0012	0.0012	0.0012 - 0.0026	0.0012
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	3,090	3,090	3,090 - 6,400	3,090
Probability of latent cancer fatality	0.001276	0.001276	0.001276 - 0.00256	0.001276
Collective dose (person-rem)	210	210	210 - 450	210
Number of latent cancer fatalities	0.084	0.084	0.084 - 0.18	0.084

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-21. Radiological health impacts from airborne radon-222 to subsurface facility workers involved in development activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	4,400	4,400	4,400	4,400
Probability of latent cancer fatality	0.0018	0.0018	0.0018	0.0018
Collective dose (person-rem)	1,200	1,200	1,300 - 1,500	1,300
Number of latent cancer fatalities	0.48	0.48	0.52 - 0.60	0.52
Noninvolved worker				
Dose to maximally exposed worker (millirem)	790	790	790	790
Probability of latent cancer fatality	0.00032	0.00032	0.00032	0.00032
Collective dose (person-rem)	72	72	79	79
Number of latent cancer fatalities	0.029	0.029	0.032	0.032
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	5,190	5,190	5,190	5,190
Probability of latent cancer fatality	0.00212	0.00212	0.00212	0.00212
Collective dose (person-rem)	1,300	1,300	1,400 - 1,600	1,400
Number of latent cancer fatalities	0.52	0.52	0.55 - 0.64	0.56

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.2.3 *Summary of Impacts for the Operations Period*

Tables F-22 and F-23 summarize the estimated safety and health impacts to workers during the operations period from industrial hazards and from radiological hazards, respectively.

Table F-22. Estimated impacts to workers from industrial hazards during the operations period.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC range	Lower-temperature DPC
Involved				
Total recordable cases of injury and illness	1,200	910	1,200 - 1,700	940
Lost workday cases	590	490	620 - 840	510
Fatalities	0.9	0.66	0.91 - 1.4	0.67
Noninvolved				
Total recordable cases of injury and illness	300	340	310 - 470	340
Lost workday cases	150	170	150 - 230	170
Fatalities	0.31	0.34	0.31 - 0.45	0.35
All workers (totals)[e]				
Total recordable cases of injury and illness	1,500	1,300	1,500 - 2,200	1,300
Lost workday cases	740	660	770 - 1,100	680
Fatalities	1.2	1.0	1.2 - 1.9	1.0

a. Source: Sum of impacts listed in Tables F-13, F-14, and F-15.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = disposal canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-23. Summary of estimated dose and radiological health impacts to workers for the repository operations period.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC range	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	15,000	15,000	15,000 - 30,000	15,000
Probability of latent cancer fatality	0.006	0.006	0.006 - 0.012	0.006
Collective dose (person-rem)	7,500	4,800	7,600 - 12,000	4,900
Number of latent cancer fatalities	3	1.9	3 - 4.8	2
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,500	1,500	1,500 - 1,800	1,500
Probability of latent cancer fatality	0.0006	0.0006	0.0006 - 0.00072	0.0006
Collective dose (person-rem)	150	150	160 - 170	160
Number of latent cancer fatalities	0.06	0.06	0.064 - 0.068	0.064
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	16,500	16,500	16,500 - 31,800	16,500
Probability of latent cancer fatality	0.0066	0.0066	0.0066 - 0.01272	0.0066
Collective dose (person-rem)	7,700	5,000	7,800 - 12,000	5,100
Number of latent cancer fatalities	3.1	2	3.1 - 4.8	2.0

a. Source: Sum of impacts listed in Tables F-16, F-17, F-18, F-19, F-20, and F-21.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.3 Occupational Health and Safety Impacts to Workers During the Monitoring and Caretaking Period

F.2.3.3.1 *Health and Safety Impacts to Workers from Workplace Industrial Hazards*

Health and safety impacts from industrial hazards common to the workplace for the monitoring period consist of the following:

- Impacts to surface facility workers for the 3-year surface facility decontamination period (Table F-24)
- Impacts to surface facility workers for monitoring support activities (Table F-25)
- Impacts to subsurface facility workers for monitoring and maintenance activities (Table F-26)

Table F-24. Industrial hazard health and safety impacts to surface facility workers during the decontamination period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	80	59	66 - 80	59
Lost workday cases	32	24	26 - 32	24
Fatalities	0.077	0.057	0.064 - 0.077	0.057
Noninvolved				
Total recordable cases of injury and illness	23	20	20 - 23	20
Lost workday cases	11	9.7	9.7 - 11	9.7
Fatalities	0.02	0.018	0.018 - 0.02	0.018
All workers (total)[e]				
Total recordable cases of injury and illness	100	79	86 - 100	79
Lost workday cases	43	34	36 - 43	34
Fatalities	0.097	0.075	0.082 - 0.97	0.075

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.3.2 *Radiological Health Impacts to Workers*

F.2.3.3.2.1 Surface Facility Workers. During monitoring, surface facility workers would be involved in two types of activities with the potential for worker exposure. They are (a) a three-year decontamination operation after the completion of emplacement, and (b) support of subsurface monitoring and caretaking activities by surface facility workers for an additional 73 years for the higher-temperature scenarios. For the lower-temperature scenarios, the lengths of the support period for monitoring and caretaking activities by surface facility workers would be 122 years for the maximum spacing scenarios and 297 years for the long-term ventilation scenarios.

Surface facility workers providing support for the subsurface monitoring and caretaking activities would receive very little exposure in comparison to their counterparts involved in the subsurface monitoring and caretaking activities (see Table F-7, footnote j).

Radiological health impacts for the workers involved in surface facility decontamination activities are listed in Table F-27.

Table F-25. Industrial hazard health and safety impacts to surface facility workers during the monitoring and caretaking period.[a,b,c,d]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[e]	DPC[f]	UC range	DPC
Involved				
Total recordable cases of injury and illness	83	83	110 - 330	330
Lost workday cases	33	33	44 - 130	130
Fatalities	0.08	0.08	0.11 - 0.32	0.32
Noninvolved				
Total recordable cases of injury and illness	0	0	0	0
Lost workday cases	0	0	0	0
Fatalities	0	0	0	0
All workers (total)[g]				
Total recordable cases of injury and illness	83	83	110 - 330	330
Lost workday cases	33	33	44 - 130	130
Fatalities	0.08	0.08	0.11 - 0.32	0.32

a. Source: Calculated using impact rates from Table F-4.
b. All workers are considered to be involved workers.
c. Includes full-time equivalent worker years for solar power generating facility monitoring and maintenance.
d. Numbers are rounded to two significant figures.
e. UC = uncanistered packaging scenario.
f. DPC = dual-purpose canister packaging scenario.
g. Totals might differ from sums of values due to rounding.

Table F-26. Industrial hazard health and safety impacts for subsurface workers during the monitoring period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	160	160	200 - 620	620
Lost workday cases	63	63	82 - 250	250
Fatalities	0.15	0.15	0.20 - 0.60	0.60
Noninvolved				
Total recordable cases of injury and illness	33	33	42 - 130	130
Lost workday cases	16	16	21 - 62	62
Fatalities	0.029	0.029	0.037 - 0.11	0.11
All workers (total)[e]				
Total recordable cases of injury and illness	190	190	240 - 750	750
Lost workday cases	79	79	100 - 310	310
Fatalities	0.18	0.18	0.24 - 0.71	0.71

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-27. Radiological health impacts to surface facility workers during facility decontamination.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Dose to maximally exposed worker (millirem)	75	75	75	75
Probability of latent cancer fatality	0.000030	0.000030	0.000030	0.000030
Collective dose (person-rem)	67	49	55 - 67	49
Number of latent cancer fatalities	0.027	0.020	0.022 - 0.027	0.020

a. Source: Dose rates from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.

F.2.3.3.2.2 Subsurface Facility Workers. There are three exposure components which contribute to radiological health impacts to subsurface facility workers during the monitoring and caretaking phase. They are exposure from radiation emanating from the waste packages, exposure from the ambient radiation emanating from the drift walls, and exposure from inhalation of radon-222 and its progeny which are present in the subsurface atmosphere. Exposures to the subsurface workers during the monitoring and caretaking phase for each of these three components are listed in Tables F-28, F-29, and F-30, respectively. Exposures to the maximally exposed individual worker were based on a maximum work period of 50 years for an individual worker when the length of the monitoring periods is longer than 50 years.

Table F-28. Radiological health impacts to subsurface facility workers from waste package exposure during the monitoring and caretaking period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	10,000	10,000	10,000	10,000
Probability of latent cancer fatality	0.0040	0.0040	0.0040	0.0040
Collective dose (person-rem)	280	280	370 - 1,100	1,100
Number of latent cancer fatalities	0.11	0.11	0.15 - 0.44	0.44
Noninvolved worker				
Dose to maximally exposed worker (millirem)	400	400	400	400
Probability of latent cancer fatality	0.00016	0.00016	0.00016	0.00016
Collective dose (person-rem)	7.9	7.9	10 - 31	31
Number of latent cancer fatalities	0.0032	0.0032	0.004 - 0.012	0.012
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	10,400	10,400	10,400	10,400
Probability of latent cancer fatality	0.00416	0.00416	0.00416	0.00416
Collective dose (person-rem)	290	290	380 - 1,100	1,100
Number of latent cancer fatalities	0.12	0.12	0.15 - 0.44	0.44

a. Source: Exposure data from Table F-6.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-29. Radiological health impacts to subsurface facility workers from ambient radiation during the monitoring and caretaking period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	2,500	2,500	2,500	2,500
Probability of latent cancer fatality	0.001	0.001	0.001	0.001
Collective dose (person-rem)	260	260	340 - 1,000	1,000
Number of latent cancer fatalities	0.10	0.10	0.14 - 0.40	0.40
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,000	1,000	1,000	1,000
Probability of latent cancer fatality	0.0004	0.0004	0.0004	0.0004
Collective dose (person-rem)	20	20	26 - 78	78
Number of latent cancer fatalities	0.008	0.008	0.01 - 0.031	0.031
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	3,500	3,500	3,500	3,500
Probability of latent cancer fatality	0.0014	0.0014	0.0014	0.0014
Collective dose (person-rem)	280	280	370 - 1,100	1,100
Number of latent cancer fatalities	0.11	0.11	0.15 - 0.44	0.44

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-30. Radiological health impacts to subsurface facility workers from inhalation of radon-222 during the monitoring and caretaking period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	5,000	5,000	5,000	5,000
Probability of latent cancer fatality	0.002	0.002	0.002	0.002
Collective dose (person-rem)	520	520	680 - 2,100	2,100
Number of latent cancer fatalities	0.21	0.21	0.27 - 0.84	0.84
Noninvolved worker				
Dose to maximally exposed worker (millirem)	400	400	400	400
Probability of latent cancer fatality	0.00016	0.00016	0.00016	0.00016
Collective dose (person-rem)	7.9	7.9	10 - 31	31
Number of latent cancer fatalities	0.0032	0.0032	0.004 - 0.012	0.012
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	5,400	5,400	5,400	5,400
Probability of latent cancer fatality	0.00216	0.00216	0.00216	0.00216
Collective dose (person-rem)	530	530	690 - 2,100	2,100
Number of latent cancer fatalities	0.21	0.21	0.28 - 0.84	0.84

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.3.3 *Summary of Health Impacts for the Monitoring Phase*

Tables F-31 and F-32 summarize health and safety impacts from industrial hazards and from radiological hazards, respectively.

Table F-31. Estimated impacts to workers from industrial hazards during the monitoring and caretaking period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	320	300	400 - 1,000	1,000
Lost workday cases	130	120	160 - 410	410
Fatalities	0.31	0.29	0.38 - 1.0	0.98
Noninvolved				
Total recordable cases of injury and illness	55	53	65 - 150	150
Lost workday cases	27	25	32 - 73	72
Fatalities	0.049	0.046	0.057 - 0.13	0.13
All workers (total)[e]				
Total recordable cases of injury and illness	380	350	470 - 1,200	1,200
Lost workday cases	160	150	190 - 480	480
Fatalities	0.36	0.34	0.44 - 1.1	1.1

a. Values presented in this table are the sum of the estimates from Tables F-24, F-25, and F-26.
b. Values are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-32. Radiological health impacts to workers for the monitoring and caretaking period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	18,000	18,000	18,000	18,000
Probability of latent cancer fatality	0.0072	0.0072	0.0072	0.0072
Collective dose (person-rem)	1,100	1,100	1,500 - 4,300	4,300
Number of latent cancer fatalities	0.44	0.44	0.6 - 1.7	1.7
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,800	1,800	1,800	1,800
Probability of latent cancer fatality	0.00072	0.00072	0.00072	0.00072
Collective dose (person-rem)	36	36	46 - 140	140
Number of latent cancer fatalities	0.014	0.014	0.018 - 0.056	0.056
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	19,800	19,800	19,800	19,800
Probability of latent cancer fatality	0.00792	0.00792	0.00792	0.00792
Collective dose (person-rem)	1,100	1,100	1,500 - 4,400	4,400
Number of latent cancer fatalities	0.44	0.44	0.6 - 1.8	1.8

a. Values in this table are the sum of the values in Tables F-27, F-28, F-29, and F-30.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.4 Occupational Health and Safety Impacts During the Closure Phase

F.2.3.4.1 *Health and Safety Impacts to Workers from Workplace Industrial Hazards*

Health and safety impacts to workers from industrial hazards common to the workplace for the closure phase are listed in Table F-33 for surface facility workers and Table F-34 for subsurface facility workers.

Table F-33. Industrial hazard health and safety impacts to surface facility workers during the closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	180	160	180	160
Lost workday cases	85	75	85	75
Fatalities	0.085	0.075	0.085	0.075
Noninvolved				
Total recordable cases of injury and illness	37	32	37	32
Lost workday cases	18	16	18	16
Fatalities	0.032	0.028	0.032	0.028
All workers (total)[e]				
Total recordable cases of injury and illness	220	190	220	190
Lost workday cases	100	91	100	91
Fatalities	0.12	0.10	0.12	0.10

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-34. Industrial hazard health and safety impacts to subsurface facility workers during the closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	150	150	160 - 250	160
Lost workday cases	69	69	76 - 120	76
Fatalities	0.069	0.069	0.076 - 0.12	0.076
Noninvolved				
Total recordable cases of injury and illness	15	15	16 - 25	16
Lost workday cases	7.2	7.2	7.9 - 12	7.9
Fatalities	0.013	0.013	0.014 - 0.022	0.014
All workers (total)[e]				
Total recordable cases of injury and illness	170	170	180 - 280	180
Lost workday cases	76	76	84 - 130	84
Fatalities	0.082	0.082	0.09 - 0.14	0.09

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.2.3.4.2 *Radiological Health Impacts to Workers*

Radiological health impact to workers from closure activities are the sum of the following components:

- Radiological health impacts to subsurface workers from radiation emanating from the waste packages during the closure phase (Table F-35)
- Radiological impacts to subsurface workers from the ambient radiation field in the drifts during the closure phase (Table F-36)
- Radiological impacts to subsurface workers from inhalation of radon-222 in the drift atmosphere during the closure phase (Table F-37)

Table F-35. Radiological health impacts to subsurface workers from radiation emanating from waste packages during closure phase.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	6,000	6,000	7,100 - 12,000	7,100
Probability of latent cancer fatality	0.0024	0.0024	0.0028 - 0.0048	0.0028
Collective dose (person-rem)	270	270	300 - 460	300
Number of latent cancer fatalities	0.11	0.11	0.12 - 0.18	0.12
Noninvolved worker				
Dose to maximally exposed worker (millirem)	80	80	88 - 140	88
Probability of latent cancer fatality	0.000032	0.000032	0.000035 - 0.000056	0.000035
Collective dose (person-rem)	3.6	3.6	4 - 6.1	4
Number of latent cancer fatalities	0.0014	0.0014	0.0016 - 0.0024	0.0016
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	6,080	6,080	7,188 - 12,140	7,188
Probability of latent cancer fatality	0.002432	0.002432	0.002835 - 0.004856	0.002835
Collective dose (person-rem)	270	270	300 - 470	300
Number of latent cancer fatalities	0.11	0.11	0.12 - 0.19	0.12

a. Source: Exposure data from Table F-6.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Because the surface facilities would be largely decontaminated at the beginning of the monitoring period (the exception would be a small facility retained to handle an operations emergency), radiological health impacts to surface facility workers during closure would be small in comparison to those to the subsurface facility workers and so are not included here.

F.2.3.4.3 *Summary of Impacts for Closure Phase*

Tables F-38 and F-39 summarize the estimated health and safety impacts from industrial hazards and from radiological hazards, respectively.

F.2.3.5 Summary of Occupational Health and Safety Impacts for All Repository Phases

The occupational health and safety impacts for all of the repository phases have been summarized in Tables F-40 (impacts from industrial safety hazards) and F-41 (impacts from radiological health hazards).

Table F-36. Radiological health impacts to subsurface workers from ambient radiation during closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	500	500	550 - 850	550
Probability of latent cancer fatality	0.0002	0.0002	0.00022 - 0.00034	0.00022
Collective dose (person-rem)	120	120	130 - 200	130
Number of latent cancer fatalities	0.048	0.048	0.052 - 0.08	0.052
Noninvolved worker				
Dose to maximally exposed worker (millirem)	200	200	220 - 340	220
Probability of latent cancer fatality	0.00008	0.00008	0.000088 - 0.00014	0.000088
Collective dose (person-rem)	9	9	9.9 - 15	9.9
Number of latent cancer fatalities	0.0036	0.0036	0.004 - 0.006	0.004
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	700	700	770 - 1,190	770
Probability of latent cancer fatality	0.00028	0.00028	0.000308 - 0.00048	0.000308
Collective dose (person-rem)	130	130	140 - 220	140
Number of latent cancer fatalities	0.052	0.052	0.056 - 0.088	0.056

a. Source: Exposure values from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-37. Radiological health impacts to subsurface workers from inhalation of radon-222 during closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	200	200	220 - 340	220
Probability of latent cancer fatality	0.00008	0.00008	0.000088 - 0.00014	0.000088
Collective dose (person-rem)	48	48	52 - 81	52
Number of latent cancer fatalities	0.019	0.019	0.021 - 0.032	0.021
Noninvolved worker				
Dose to maximally exposed worker (millirem)	80	80	88 - 140	88
Probability of latent cancer fatality	0.000032	0.000032	0.000035 - 0.000056	0.000035
Collective dose (person-rem)	3.6	3.6	4 - 6.1	4
Number of latent cancer fatalities	0.0014	0.0014	0.0016 - 0.0024	0.0016
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	280	280	308 - 480	308
Probability of latent cancer fatality	0.000112	0.000112	0.000123- 0.000196	0.000123
Collective dose (person-rem)	52	52	56 - 87	56
Number of latent cancer fatalities	0.021	0.021	0.022 - 0.035	0.022

a. Source: Exposure values from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-38. Summary of estimates of impacts to workers from industrial hazards for the closure phase.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	320	300	340 - 420	320
Lost workday cases	150	140	160 - 200	150
Fatalities	0.15	0.14	0.16 - 0.2	0.15
Noninvolved				
Total recordable cases of injury and illness	51	47	53 - 62	49
Lost workday cases	25	23	26 - 30	24
Fatalities	0.045	0.041	0.047 - 0.054	0.043
All workers (total)[e]				
Total recordable cases of injury and illness	370	350	390 - 480	370
Lost workday cases	180	160	190 - 230	170
Fatalities	0.20	0.18	0.21 - 0.25	0.19

a. Data in this table are the sum of the impacts in Tables F-33 and F-34.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-39. Summary of radiological health impacts to subsurface workers for the closure phase.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	6,700	6,700	7,900 - 13,000	7,900
Probability of latent cancer fatality	0.0027	0.0027	0.0032 - 0.0052	0.0032
Collective dose (person-rem)	430	430	480 - 740	480
Number of latent cancer fatalities	0.17	0.17	0.19 - 0.3	0.19
Noninvolved worker				
Dose to maximally exposed worker (millirem)	360	360	400 - 610	400
Probability of latent cancer fatality	0.00014	0.00014	0.00016 - 0.00024	0.00016
Collective dose (person-rem)	16	16	18 - 28	18
Number of latent cancer fatalities	0.0064	0.0064	0.0072 - 0.011	0.0072
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	7,060	7,060	8,300 - 13,610	8,300
Probability of latent cancer fatality	0.00284	0.00284	0.00336 - 0.00544	0.00336
Collective dose (person-rem)	450	450	500 - 770	500
Number of latent cancer fatalities	0.18	0.18	0.2 - 0.31	0.2

a. Data in this table are the sum of the impacts presented in Tables F-35, F-36, and F-37, except for impacts to maximally exposed individuals.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-package canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-40. Summary of impacts to workers from industrial hazards for all phases.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved				
Total recordable cases of injury and illness	2,200	1,800	2,500 - 3,300	2,600
Lost workday cases	1,000	910	1,200 - 1,500	1,200
Fatalities	1.5	1.2	1.8 - 2.6	2
Noninvolved				
Total recordable cases of injury and illness	470	490	500 - 720	590
Lost workday cases	230	240	250 - 350	290
Fatalities	0.45	0.47	0.48 - 0.68	0.56
All workers (total)[e]				
Total recordable cases of injury and illness	2,700	2,300	3,000 - 4,000	3,200
Lost workday cases	1,200	1,200	1,500 - 1,900	1,500
Fatalities	2.0	1.7	2.3 - 3.3	2.6

a. Estimated impacts in this table are the sums of impacts listed in Tables F-12, F-22, F-31, and F-38.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-41. Summary of radiological health impacts to workers for all phases.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC range	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	18,000	18,000	18,000 - 30,000	18,000
Probability of latent cancer fatality	0.0072	0.0072	0.0072 - 0.012	0.0072
Collective dose (person-rem)	9,800	7,000	11,000 - 17,000	10,000
Number of latent cancer fatalities	3.9	2.8	4.4 - 6.8	4
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,800	1,800	1,800	1,800
Probability of latent cancer fatality	0.00072	0.00072	0.00072	0.00072
Collective dose (person-rem)	230	230	280 - 360	350
Number of latent cancer fatalities	0.092	0.092	0.11 - 0.14	0.14
All workers (totals)[e]				
Dose to maximally exposed worker (millirem)	20,000	20,000	20,000 - 30,000	20,000
Probability of latent cancer fatality	0.0079	0.0079	0.0079 - 0.012	0.0079
Collective dose (person-rem)	10,000	7,200	11,000 - 17,000	10,000
Number of latent cancer fatalities	4.0	2.9	4.4 - 6.8	4.0

a. Estimated impacts in this table are the sums of the impacts listed in Tables F-11, F-23, F-32, and F-39.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3 Worker Human Health and Safety Impact Analysis for Inventory Modules 1 and 2

DOE performed the same analyses used for the Proposed Action to estimate the occupational and public health and safety impacts from the emplacement of Inventory Module 1 or 2. Module 1 would involve the emplacement of additional spent nuclear fuel and high-level radioactive waste in the repository; Inventory Module 2 would emplace commercial Greater-Than-Class-C waste and DOE Special-Performance-Assessment-Required waste, which is equivalent to commercial Greater-Than-Class-C waste, in addition to the inventory from Module 1. The volumes of Greater-Than-Class-C and Special-Performance-Assessment-Required waste would be less than that for spent nuclear fuel and high-level radioactive waste (DIRS 104508-CRWMS M&O 1999, Table 3.1). Waste packages containing these materials would be placed between the waste packages containing spent nuclear fuel and high-level radioactive waste (see Chapter 8, Section 8.1.2.1).

With regard to estimating heath and safety impacts for the inventory modules, the characteristics of the spent nuclear fuel and high-level radioactive waste were taken to be the same as those for the Proposed Action, but there would be more material to emplace (see Appendix A, Section A.2). As described in Appendix A, the radiological content of the Greater-Than-Class-C waste and Special-Performance-Assessment-Required waste, which is the additional material in Module 2, is much less than that for spent nuclear fuel and high-level radioactive waste. Therefore, the emplacement of the Module 2 material would not meaningfully increase radiological impacts to workers over those estimated for the Module 1 inventory. Further, the facility design parameters, on which the impact estimates are based, are extrapolations from existing designs and have some uncertainty associated with them [see, for example, DIRS 104508-CRWMS M&O (1999), Section 6.2, first paragraph]. Therefore, separate occupational and public health and safety impact analyses were not performed for Module 2 because the impacts for Inventory Modules 1 and 2 would not differ meaningfully.

The calculation of health and safety impacts to workers assumed that the throughput rate of materials for the facility would remain the same as that assumed for the Proposed Action during repository operations (that is, the 70,000-MTHM case). In addition, for the inventory modules the period of operations would be extended to accommodate the additional materials, and the monitoring period would be reduced such that the Yucca Mountain repository operations and monitoring activities would be the same as those for the Proposed Action.

This section discusses the methodologies and data used to estimate occupational radiological health and safety impacts resulting from construction, operation and monitoring, and closure of the Yucca Mountain Repository for Inventory Modules 1 and 2, and presents the detailed results. Section F.3.1 describes the methods DOE used to estimate impacts. Section F.3.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources. Section F.3.3 contains detailed tabulations of results.

F.3.1 METHODOLOGY FOR CALCULATING HUMAN HEALTH AND SAFETY IMPACTS

DOE used the methodology described in Section F.2.1 to estimate health and safety impacts for the inventory modules. This methodology involved assembling data for the number of full-time equivalent workers for each repository phase. These numbers were used with statistics for the likelihood of an impact (industrial hazards) or the expected dose rate in the worker environment to calculate health and safety impacts. The way in which the input data was combined in the calculation of health and safety impacts is described in more detail in Section F.2.1. Some of the input data for the calculations for the inventory modules are different from those for the Proposed Action, as discussed in the next section.

F.3.2 DATA SOURCES AND TABULATIONS

F.3.2.1 Full-Time Equivalent Worker-Year Estimates for the Repository Phases for Inventory Modules 1 and 2

The full-time equivalent worker-year estimates for the inventory modules are different from those for the Proposed Action. Table F-42 lists the number of full-time equivalent work years for the various repository phases for the inventory modules. Each full-time equivalent work year represents 2,000 work hours, the hours assumed to be worked in a normal work year.

This analysis divides the repository workforce into two groups—involved and noninvolved workers (see Section F.2 for definitions of involved and noninvolved workers). It did not consider workers whose place of employment would be other than at the repository site.

F.3.2.2 Statistics on Health and Safety Impacts from Industrial Hazards in the Workplace

DOE used the same statistics for health and safety impacts from industrial hazards common to the workplace that were used for the Proposed Action (70,000 MTHM) for analyzing the inventory module impacts (see Tables F-4 and F-5).

F.3.2.3 Estimates of Radiological Exposure Rates and Times for Inventory Modules 1 and 2

DOE used the values in Tables F-6 through F-8 (Proposed Action) for exposure rates, occupancy times, and the fraction of the workforce that would be exposed to estimate radiological health impacts for the inventory module cases, except for doses from the waste packages and from radon-222 inhalation for the subsurface emplacement, monitoring, and closure phases.

F.3.3 DETAILED HUMAN HEALTH AND SAFETY IMPACTS TO WORKERS–INVENTORY MODULES 1 AND 2

F.3.3.1 Construction Phase

F.3.3.1.1 *Industrial Hazards to Workers*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the construction phase. Because the activities for construction would be the same for the Inventory Modules as they would for the Proposed Action, the industrial safety impacts would also be the same. Impact values for surface workers are presented in Table F-9, while impacts for subsurface workers are presented in Table F-10. Further, Table F-12 summarizes the impacts listed in Tables F-9 and F-10.

F.3.3.1.2 *Radiological Health Impacts to Workers*

Because the activities for construction would be the same for the Inventory Modules as for the Proposed Action, the radiological impacts are also the same. Table F-11 lists subsurface worker health impacts from inhalation of radon-222 and its decay products in the subsurface atmosphere and from exposure to natural radiation from radionuclides in the drift walls, respectively. The radiological health impacts to surface workers from radon-222 and ambient radiation contribute negligibly to the overall impact from these natural sources. Therefore, separate tables are not presented for surface workers.

Table F-42. Full-time equivalent worker years for various repository periods for Inventory Modules 1 and 2 (page 1 of 2).[a]

				Operating mode			
				Higher-temperature		Lower-temperature	
Phase	Subphase	Period	Worker group	UC[b]	DPC[c]	UC (range)	DPC
Construction	Surface	44 months	Involved	2,800	2,500	2,600 - 2,900	2,500
			Noninvolved	1,100	940	990 - 1,100	940
	Subsurface	5 years	Involved	2,700	2,700	2,700	2,700
			Noninvolved	560	560	560	560
	Solar power facility	6 years	Involved	76	76	76	76
			Noninvolved	26	26	26	26
	Aging facilities	16 years	Involved	N/A[d]	N/A	750	N/A
			Noninvolved	N/A	N/A	290	N/A
	Construction subtotals			7,300	6,800	7,300 - 8,000	6,800
Operations	Surface handling	First 38 years	Involved	37,000	23,000	37,000 - 38,000	23,000
			Noninvolved	13,000	15,000	13,000	15,000
		Last 13 years (aging only)	Involved	N/A	N/A	6,400	N/A
			Noninvolved	N/A	N/A	2,200	N/A
	Subsurface emplacement	First 38 years	Involved	2,800	2,800	2,800 - 4,300	2,800
			Noninvolved	610	610	610 - 930	610
		Last 13 years (aging only)	Involved	N/A	N/A	960	N/A
			Noninvolved	N/A	N/A	210	N/A
	Subsurface development	36 years	Involved	10,000	10,000	10,000 - 11,000	10,000
			Noninvolved	2,400	2,400	2,400	2,400
	Operations subtotals			66,000	54,000	66,000 - 77,000	54,000
Monitoring	Surface facility decontamination	3 years	Involved	2,700	2,000	2,200 - 2,700	2,000
			Noninvolved	690	610	610 - 690	610
	Surface	Variable[e]	Involved	2,100	2,100	3,800 - 10,000	10,000
			Noninvolved	0	0	0	0
	Subsurface	Variable[f]	Involved	4,700	4,700	8,100 - 23,000	23,000
			Noninvolved	870	870	1,600 - 4,200	4,200
	Solar panel maintenance	Variable[g]	Involved	180	180	290 - 610	610
	Solar panel replacement	Every 20 years	Involved	36	36	72 - 140	140
	Monitoring subtotals			11,000	10,000	17,000 - 41,000	40,000

Table F-42. Full-time equivalent worker years for various repository periods for Inventory Modules 1 and 2 (page 2 of 2).[a]

				Operating mode			
				Higher-temperature		Lower-temperature	
Phase	Subphase	Period	Worker group	UC[b]	DPC[c]	UC (range)	DPC
Closure	Surface facilities	6 years	Involved	2,900	2,500	2,900	2,500
			Noninvolved	1,100	950	1,100	950
	Subsurface	Variable[h]	Involved	2,900	2,900	3,600 - 6,900	3,800
			Noninvolved	540	540	680 - 1,400	720
	Solar power facility	6 years	Involved	62	62	62	62
			Noninvolved	24	24	24	24
	Closure subtotals			7,400	6,900	8,300 - 12,000	8,100
Totals				***92,000***	***78,000***	***110,000 - 130,000***	***110,000***

a. Sources: Derived from DIRS 152010-CRWMS M&O (2000, all); DIRS 150941-CRWMS M&O (2000, all); DIRS 155515-Williams (2001, all); DIRS 155516-Williams (2001, all); DIRS 153882-Griffith (2001, all); DIRS 154758-Lane (2000, all); DIRS 153958-Morton (2000, all).

b. UC = uncanistered packaging scenario.

c. DPC = dual-purpose canister packaging scenario.

d. N/A = not applicable.

e. Surface monitoring periods are 73 years for the higher-temperature cases (UC and DPC), 297 years for the lower-temperature DPC case, and ranges from 96 to 271 years for the remaining cases.

f. Subsurface monitoring periods are 76 years for the higher-temperature cases (UC and DPC), 300 years for the lower-temperature DPC case, and ranges from 99 to 274 years for the remaining cases.

g. Solar power maintenance periods are 100 years for the higher-temperature cases (UC and DPC), 324 years for the lower-temperature DPC case, and either 149 or 324 years for the remaining cases.

h. Subsurface closure periods are 10 years for the higher-temperature cases (UC and DPC), 11 years for the lower-temperature DPC case, and either 12 or 17 years for the remaining cases.

F.3.3.2 Operations Period

F.3.3.2.1 *Health and Safety Impacts to Workers from Industrial Hazards*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the operations period. These impacts would consist of three components:

- Health and safety impacts to surface workers for operations (Table F-43)
- Health and safety impacts to subsurface workers for drift development (Table F-44)
- Health and safety impacts to subsurface workers for emplacement (Table F-45)

Table F-43. Industrial hazard health and safety impacts for surface facility workers during the operations period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	1,100	700	1,100 - 1,300	700
Lost workday cases	440	280	440 - 520	280
Fatalities	1.1	0.68	1.1 - 1.3	0.68
Noninvolved workers				
Total recordable cases of injury and illness	430	490	430 - 500	490
Lost workday cases	210	240	210 - 240	240
Fatalities	0.38	0.43	0.38 - 0.44	0.43
All workers[e]				
Total recordable cases of injury and illness	1,500	1,200	1,500 - 1,800	1,200
Lost workday cases	650	520	650 - 760	520
Fatalities	1.5	1.1	1.5 - 1.7	1.1

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.2.2 *Radiological Health Impacts to Workers*

This section details radiological health impacts to workers during the operation and monitoring phase for the inventory modules. These impacts consist of three components:

- Radiological health impacts to surface workers from waste packages during operations (Table F-46)
- Radiological health impacts to subsurface workers involved in drift development activities (Tables F-47 and F-48)
- Radiological health impacts to subsurface workers involved in emplacement activities (Tables F-49 through F-51)

Table F-44. Industrial hazard health and safety impacts to subsurface facility workers involved in drift development activities.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	DPC[d]	Lower-temperature UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	700	700	700 - 760	700
Lost workday cases	490	490	490 - 540	490
Fatalities	0.3	0.3	0.3 - 0.33	0.3
Noninvolved workers				
Total recordable cases of injury and illness	27	27	27	27
Lost workday cases	17	17	17	17
Fatalities	0.071	0.071	0.071	0.071
All workers[e]				
Total recordable cases of injury and illness	730	730	730 - 790	730
Lost workday cases	510	510	510 - 560	510
Fatalities	0.37	0.37	0.37 - 0.4	0.37

a. Source: Calculated using impact rates from Table F-5.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-45. Industrial hazard health and safety impacts to subsurface facility workers involved in emplacement activities.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	DPC[d]	Lower-temperature UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	84	84	84 - 130	84
Lost workday cases	34	34	34 - 51	34
Fatalities	0.082	0.082	0.082 - 0.12	0.082
Noninvolved workers				
Total recordable cases of injury and illness	20	20	20 - 31	20
Lost workday cases	9.7	9.7	9.7 - 15	9.7
Fatalities	0.018	0.018	0.018 - 0.027	0.018
All workers[e]				
Total recordable cases of injury and illness	100	100	100 - 160	100
Lost workday cases	44	44	44 - 66	44
Fatalities	0.1	0.1	0.1 - 0.15	0.1

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-46. Radiological health impacts from waste packages to surface facility workers during operations period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	15,000	15,000	15,000 - 20,000	15,000
Probability of latent cancer fatality	0.006	0.006	0.006 - 0.008	0.006
Collective dose (person-rem)	8,800	4,400	8,800 - 11,000	4,400
Number of latent cancer fatalities	3.5	1.8	3.5 - 4.4	1.8
Noninvolved worker				
Dose to maximally exposed worker (millirem)	0	0	0	0
Probability of latent cancer fatality	0	0	0	0
Collective dose (person-rem)	0	0	0	0
Number of latent cancer fatalities	0	0	0	0
All workers[e]				
Collective dose (person-rem)	8,800	4,400	8,800 - 11,000	4,400
Number of latent cancer fatalities	3.5	1.8	3.5 - 4.4	1.8

a. Source: Calculated using exposure rate from Table F-8.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-47. Radiological health impacts from ambient radiation to subsurface facility workers involved in drift development activities.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	1,800	1,800	1,800	1,800
Probability of latent cancer fatality	0.00072	0.00072	0.00072	0.00072
Collective dose (person-rem)	510	510	510 - 560	510
Number of latent cancer fatalities	0.2	0.2	0.2 - 0.22	0.2
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,100	1,100	1,100	1,100
Probability of latent cancer fatality	0.00044	0.00044	0.00044	0.00044
Collective dose (person-rem)	73	73	73	73
Number of latent cancer fatalities	0.029	0.029	0.029	0.029
All workers[e]				
Collective dose (person-rem)	580	580	580 - 630	580
Number of latent cancer fatalities	0.23	0.23	0.23 - 0.25	0.23

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-48. Radiological health impacts from radon exposure to subsurface facility workers involved in drift development activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	7,200	7,200	7,200	7,200
Probability of latent cancer fatality	0.0029	0.0029	0.0029	0.0029
Collective dose (person-rem)	2,100	2,100	2,100 - 2,200	2,100
Number of latent cancer fatalities	0.84	0.84	0.84 - 0.88	0.84
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,300	1,300	1,300	1,300
Probability of latent cancer fatality	0.00052	0.00052	0.00052	0.00052
Collective dose (person-rem)	88	88	88	88
Number of latent cancer fatalities	0.035	0.035	0.035	0.035
All workers[e]				
Collective dose (person-rem)	2,200	2,200	2,200 - 2,300	2,200
Number of latent cancer fatalities	0.88	0.88	0.88 - 0.92	0.88

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-49. Radiological health impacts from waste packages to subsurface facility workers involved in emplacement activities.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	18,000	18,000	18,000 - 24,000	18,000
Probability of latent cancer fatality	0.0072	0.0072	0.0072 - 0.0096	0.0072
Collective dose (person-rem)	230	230	230 - 340	230
Number of latent cancer fatalities	0.092	0.092	0.092 - 0.14	0.092
Noninvolved worker				
Dose to maximally exposed worker (millirem)	300	300	300 - 410	300
Probability of latent cancer fatality	0.00012	0.00012	0.00012 - 0.00016	0.00012
Collective dose (person-rem)	4.9	4.9	4.9 - 7.4	4.9
Number of latent cancer fatalities	0.002	0.002	0.002 - 0.003	0.002
All workers[e]				
Collective dose (person-rem)	230	230	230 - 350	230
Number of latent cancer fatalities	0.092	0.092	0.092 - 0.14	0.092

a. Source: Exposure data from Table F-6.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-50. Radiological health impacts from ambient radiation to subsurface facility workers involved in emplacement activities.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	1,900	1,900	1,900 - 2,600	1,900
Probability of latent cancer fatality	0.00076	0.00076	0.00076 - 0.001	0.00076
Collective dose (person-rem)	140	140	140 - 210	140
Number of latent cancer fatalities	0.056	0.056	0.056 - 0.084	0.056
Noninvolved worker				
Dose to maximally exposed worker (millirem)	760	760	760 - 1,000	760
Probability of latent cancer fatality	0.0003	0.0003	0.0003 - 0.0004	0.0003
Collective dose (person-rem)	12	12	12 - 19	12
Number of latent cancer fatalities	0.0048	0.0048	0.0048 - 0.0076	0.0048
All workers[e]				
Collective dose (person-rem)	150	150	150 - 230	150
Number of latent cancer fatalities	0.06	0.06	0.06 - 0.092	0.06

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-51. Radiological health impacts from radon exposure to subsurface facility workers involved in emplacement activities.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	4,600	4,600	4,600 - 6,100	4,600
Probability of latent cancer fatality	0.0018	0.0018	0.0018 - 0.0024	0.0018
Collective dose (person-rem)	340	340	340 - 510	340
Number of latent cancer fatalities	0.14	0.14	0.14 - 0.2	0.14
Noninvolved worker				
Dose to maximally exposed worker (millirem)	300	300	300 - 410	300
Probability of latent cancer fatality	0.00012	0.00012	0.00012 - 0.00016	0.00012
Collective dose (person-rem)	4.9	4.9	4.9 - 7.4	4.9
Number of latent cancer fatalities	0.002	0.002	0.002 - 0.003	0.002
All workers[e]				
Collective dose (person-rem)	340	340	340 - 520	340
Number of latent cancer fatalities	0.14	0.14	0.14 - 0.21	0.14

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.2.3 *Summary of Impacts for the Operations Period*

Tables F-52 and F-53 present the occupational and radiological impacts, respectively, to all workers from operations activities. In each table, impacts are presented for the higher-temperature repository operating mode uncanistered and dual-purpose canister packaging scenarios; in addition, the range of impacts for the lower-temperature mode (uncanistered packaging scenario) is presented along with the impacts for the dual-purpose canister scenario that uses long-term ventilation without aging.

Table F-52. Summary of industrial hazard health and safety impacts to facility workers during operations period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Impact	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	1,900	1,500	1,900 - 2,200	1,500
Lost workday cases	970	810	970 - 1,100	810
Fatalities	1.4	1.1	1.4 - 1.7	1.1
Noninvolved workers				
Total recordable cases of injury and illness	470	530	470 - 560	530
Lost workday cases	230	260	230 - 270	260
Fatalities	0.46	0.52	0.46 - 0.54	0.52
All workers[e]				
Total recordable cases of injury and illness	2,400	2,000	2,400 - 2,800	2,000
Lost workday cases	1,200	1,100	1,200 - 1,400	1,100
Fatalities	1.9	1.6	1.9 - 2.2	1.6

a. Sources: Tables F-43, F-44, and F-45.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-53. Summary of radiological health impacts to workers from all activities during operations period.

	Operating mode			
	Higher-temperature		Lower-temperature	
Impact	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	24,000	24,000	24,000 - 33,000	24,000
Probability of latent cancer fatality	0.0096	0.0096	0.0096 - 0.013	0.0096
Collective dose (person-rem)	12,000	7,700	12,000 - 15,000	7,700
Number of latent cancer fatalities	4.8	3.1	4.8 - 6	3.1
Noninvolved worker				
Dose to maximally exposed worker (millirem)	2,400	2,400	2,400	2,400
Probability of latent cancer fatality	0.00096	0.00096	0.00096	0.00096
Collective dose (person-rem)	180	180	180 - 190	180
Number of latent cancer fatalities	0.072	0.072	0.072 - 0.076	0.072
All workers[e]				
Collective dose (person-rem)	12,000	7,900	12,000 - 15,000	7,900
Number of latent cancer fatalities	4.8	3.2	4.8 - 6	3.2

a. Sources: Tables F-46, F-47, F-48, F-49, and F-50.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.3 Occupational Health and Safety Impacts to Workers During the Monitoring and Caretaking Period

F.3.3.3.1 *Health and Safety Impacts to Workers from Workplace Industrial Hazards*

Health and safety impacts from industrial hazards common to the workplace for the monitoring period consist of the following:

- Impacts to surface facility workers for the 3-year surface facility decontamination period. These values, which are the same as those for the Proposed Action, are listed in Table F-24.
- Impacts to surface facility workers for monitoring support activities (Table F-54)
- Impacts to subsurface facility workers for monitoring and maintenance activities (Table F-55)

Table F-54. Industrial hazard health and safety impacts to surface facility workers during the monitoring period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	68	68	130 - 330	330
Lost workday cases	27	27	50 - 130	130
Fatalities	0.066	0.066	0.12 - 0.32	0.32
Noninvolved workers				
Total recordable cases of injury and illness	0	0	0	0
Lost workday cases	0	0	0	0
Fatalities	0	0	0	0
All workers[e]				
Total recordable cases of injury and illness	68	68	130 - 330	330
Lost workday cases	27	27	50 - 130	130
Fatalities	0.066	0.066	0.12 - 0.32	0.32

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.3.2 *Radiological Health Impacts to Workers*

F.3.3.3.2.1 Surface Facility Workers. During monitoring, surface facility workers would be involved in two types of activities with the potential for worker exposure. They are (a) the decontamination operation after the completion of emplacement, and (b) support of subsurface monitoring and caretaking activities by surface facility workers. Surface facility workers providing support for the subsurface monitoring and caretaking activities would receive very little radiological dose in comparison to their counterparts involved in the subsurface monitoring and caretaking activities because the greatest source of radiation exposure would be in the subsurface areas.

Radiological health impacts for the workers involved in surface facility decontamination activities, which are the same for the Inventory Modules as those for the Proposed Action, are listed in Table F-27.

Table F-55. Industrial hazard health and safety impacts to subsurface facility workers during the monitoring period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	140	140	240 - 680	680
Lost workday cases	56	56	97 - 270	270
Fatalities	0.13	0.13	0.23 - 0.65	0.65
Noninvolved workers				
Total recordable cases of injury and illness	29	29	52 - 140	140
Lost workday cases	14	14	25 - 67	67
Fatalities	0.025	0.025	0.045 - 0.12	0.12
All workers[e]				
Total recordable cases of injury and illness	170	170	290 - 820	820
Lost workday cases	70	70	120 - 340	340
Fatalities	0.16	0.16	0.28 - 0.77	0.77

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.3.2.2 Subsurface Facility Workers. There are three exposure components which contribute to radiological health impacts to subsurface facility workers during the monitoring and caretaking phase. They are exposure from radiation emanating from the waste packages, exposure from the ambient radiation emanating from the drift walls, and exposure from inhalation of radon-222 and its progeny which are present in the subsurface atmosphere. Exposures to the subsurface workers during the monitoring and caretaking phase for each of these three components are listed in Tables F-56, F-57, and F-58, respectively. Exposures to the maximally exposed worker were based on a maximum work period of 50 years for an individual worker when the length of the monitoring periods was longer than 50 years.

Table F-56. Radiological health impacts to subsurface facility workers from exposure to waste packages during the monitoring and caretaking period.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	10,000	10,000	10,000	10,000
Probability of latent cancer fatality	0.004	0.004	0.004	0.004
Collective dose (person-rem)	230	230	410 - 1,100	1,100
Number of latent cancer fatalities	0.092	0.092	0.16 - 0.44	0.44
Noninvolved worker				
Dose to maximally exposed worker (millirem)	400	400	400	400
Probability of latent cancer fatality	0.00016	0.00016	0.00016	0.00016
Collective dose (person-rem)	6.9	6.9	13 - 34	34
Number of latent cancer fatalities	0.0028	0.0028	0.0052 - 0.014	0.014
All workers[e]				
Collective dose (person-rem)	240	240	420 - 1,100	1,100
Number of latent cancer fatalities	0.096	0.096	0.17 - 0.44	0.44

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-57. Radiological health impacts to subsurface facility workers from ambient radiation exposure during the monitoring and caretaking period.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC (range)	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	2,500	2,500	2,500	2,500
Probability of latent cancer fatality	0.001	0.001	0.001	0.001
Collective dose (person-rem)	230	230	400 - 1,100	1,100
Number of latent cancer fatalities	0.092	0.092	0.16 - 0.44	0.44
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,000	1,000	1,000	1,000
Probability of latent cancer fatality	0.0004	0.0004	0.0004	0.0004
Collective dose (person-rem)	17	17	31 - 84	84
Number of latent cancer fatalities	0.0068	0.0068	0.012 - 0.034	0.034
All workers[e]				
Collective dose (person-rem)	250	250	430 - 1,200	1,200
Number of latent cancer fatalities	0.1	0.1	0.17 - 0.48	0.48

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-58. Radiological health impacts to subsurface facility workers from radon exposure during the monitoring and caretaking period.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC (range)	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	5,000	5,000	5,000	5,000
Probability of latent cancer fatality	0.002	0.002	0.002	0.002
Collective dose (person-rem)	470	470	810 - 2,300	2,300
Number of latent cancer fatalities	0.19	0.19	0.32 - 0.92	0.92
Noninvolved worker				
Dose to maximally exposed worker (millirem)	400	400	400	400
Probability of latent cancer fatality	0.00016	0.00016	0.00016	0.00016
Collective dose (person-rem)	6.9	6.9	13 - 34	34
Number of latent cancer fatalities	0.0028	0.0028	0.0052 - 0.014	0.014
All workers[e]				
Collective dose (person-rem)	480	480	820 - 2,300	2,300
Number of latent cancer fatalities	0.19	0.19	0.33 - 0.92	0.92

a. Source: Exposure data from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.3.3 *Summary of Health Impacts for the Monitoring and Caretaking Period*

Tables F-59 and F-60 present the occupational and radiological impacts, respectively, to all workers from monitoring and caretaking activities. In each table, impacts are presented for the higher-temperature uncanistered and dual-purpose canister packaging scenarios; in addition, the range of impacts for the lower-temperature uncanistered packaging scenario is presented along with the impacts for the dual-purpose canister packaging scenario with long-term ventilation.

Table F-59. Summary of industrial hazard health and safety impacts to facility workers during monitoring period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	290	270	450 - 1,100	1,100
Lost workday cases	120	110	180 - 440	430
Fatalities	0.28	0.26	0.43 - 1.1	1
Noninvolved workers				
Total recordable cases of injury and illness	51	49	74 - 160	160
Lost workday cases	25	24	36 - 78	77
Fatalities	0.045	0.043	0.065 - 0.14	0.14
All workers[e]				
Total recordable cases of injury and illness	340	320	520 - 1,300	1,300
Lost workday cases	150	130	220 - 520	510
Fatalities	0.33	0.3	0.5 - 1.2	1.1

a. Sources: Calculated using impact rates from Tables F-24, F-54, and F-55.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-60. Summary of radiological health impacts to workers from all activities during monitoring period.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	18,000	18,000	18,000	18,000
Probability of latent cancer fatality	0.0072	0.0072	0.0072	0.0072
Collective dose (person-rem)	990	980	1,700 - 4,500	4,500
Number of latent cancer fatalities	0.4	0.39	0.68 - 1.8	1.8
Noninvolved worker				
Dose to maximally exposed worker (millirem)	1,800	1,800	1,800	1,800
Probability of latent cancer fatality	0.00072	0.00072	0.00072	0.00072
Collective dose (person-rem)	31	31	56 - 150	150
Number of latent cancer fatalities	0.012	0.012	0.022 - 0.06	0.06
All workers[e]				
Collective dose (person-rem)	1,000	1,000	1,800 - 4,700	4,700
Number of latent cancer fatalities	0.4	0.4	0.72 - 1.9	1.9

a. Sources: Calculated using impact rates from Tables F-27, F-56, F-57, and F-58.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.4 Closure Phase

F.3.3.4.1 *Health and Safety Impacts to Workers from Industrial Hazards*

This section details health and safety impacts to workers from industrial hazards common to the workplace for the closure phase. The impacts would consist of two components—impacts to surface workers supporting the closure operations, and impacts to subsurface workers during the closure phase. These impacts are listed in Tables F-61 and F-62, respectively.

Table F-61. Industrial hazard health and safety impacts to surface facility workers during the closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	180	160	180	160
Lost workday cases	85	75	85	75
Fatalities	0.085	0.075	0.085	0.075
Noninvolved workers				
Total recordable cases of injury and illness	37	32	37	32
Lost workday cases	18	16	18	16
Fatalities	0.032	0.028	0.032	0.028
All workers[e]				
Total recordable cases of injury and illness	220	190	220	190
Lost workday cases	100	91	100	91
Fatalities	0.12	0.1	0.12	0.1

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-62. Health and safety impacts to subsurface facility workers from industrial hazards during the closure phase.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	170	170	220 - 420	230
Lost workday cases	83	83	100 - 200	110
Fatalities	0.083	0.083	0.1 - 0.2	0.11
Noninvolved workers				
Total recordable cases of injury and illness	18	18	22 - 46	24
Lost workday cases	8.6	8.6	11 - 22	12
Fatalities	0.016	0.016	0.02 - 0.04	0.021
All workers[e]				
Total recordable cases of injury and illness	190	190	240 - 470	250
Lost workday cases	92	92	110 - 220	120
Fatalities	0.099	0.099	0.12 - 0.24	0.13

a. Source: Calculated using impact rates from Table F-4.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.4.2 *Radiological Health Impacts to Workers*

Radiological health impact to workers from closure activities are the sum of the following components:

- Radiological health impacts to subsurface workers from radiation emanating from the waste packages during the closure phase (Table F-63)
- Radiological impacts to subsurface workers from the ambient radiation field in the drifts during the closure phase (Table F-64)
- Radiological impacts to subsurface workers from inhalation of radon-222 in the drift atmosphere during the closure phase (Table F-65)

Table F-63. Radiological health impacts to subsurface facility workers from waste package exposure during closure phase.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC (range)	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	7,200	7,200	9,700 - 16,000	10,000
Probability of latent cancer fatality	0.0029	0.0029	0.0039 - 0.0064	0.004
Collective dose (person-rem)	320	320	410 - 620	430
Number of latent cancer fatalities	0.13	0.13	0.16 - 0.25	0.17
Noninvolved worker				
Dose to maximally exposed worker (millirem)	96	96	120 - 180	130
Probability of latent cancer fatality	0.000038	0.000038	0.000048 - 0.000072	0.000052
Collective dose (person-rem)	4.3	4.3	5.4 - 11	5.8
Number of latent cancer fatalities	0.0017	0.0017	0.0022 - 0.0044	0.0023
All workers[e]				
Collective dose (person-rem)	320	320	420 - 630	440
Number of latent cancer fatalities	0.13	0.13	0.17 - 0.25	0.18

a. Source: Exposure rates from Table F-6.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Because the surface facilities would be largely decontaminated at the beginning of the monitoring period (the exception would be a small facility retained to handle an operations emergency), radiological health impacts to surface facility workers during closure would be small in comparison to those to the subsurface facility workers and so are not included here. DOE estimated exposures to subsurface workers from waste packages by increasing those from the Proposed Action by the ratio of the length of closure phases.

F.3.3.4.3 *Summary of Impacts for Closure Phase*

Tables F-66 and F-67 present the occupational and radiological impacts, respectively, to all workers from activities performed during the closure phase. In each table, impacts are presented for the higher-temperature uncanistered and dual-purpose canister packaging scenarios; in addition, the range of impacts for the lower-temperature uncanistered packaging scenario is presented along with the impacts for the dual-purpose canister packaging scenario with long-term ventilation without aging.

Table F-64. Radiological health impacts to subsurface facility workers from ambient radiation exposure during closure phase.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC (range)	Lower-temperature DPC
Involved worker				
Dose to maximally exposed worker (millirem)	600	600	750 - 1,200	800
Probability of latent cancer fatality	0.00024	0.00024	0.0003 - 0.00048	0.00032
Collective dose (person-rem)	140	140	180 - 350	190
Number of latent cancer fatalities	0.056	0.056	0.072 - 0.14	0.076
Noninvolved worker				
Dose to maximally exposed worker (millirem)	240	240	300 - 460	320
Probability of latent cancer fatality	0.000096	0.000096	0.00012 - 0.00018	0.00013
Collective dose (person-rem)	11	11	14 - 28	14
Number of latent cancer fatalities	0.0044	0.0044	0.0056 - 0.011	0.0056
All workers[e]				
Collective dose (person-rem)	150	150	190 - 380	200
Number of latent cancer fatalities	0.06	0.06	0.076 - 0.15	0.08

a. Source: Exposure rates from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-65. Radiological health impacts to subsurface facility workers from radon exposure during closure phase.[a,b]

Worker group	Operating mode: Higher-temperature UC[c]	Higher-temperature DPC[d]	Lower-temperature UC (range)	Lower-temperature DPC
Involved worker				
Full-time equivalent worker years[e]	2,900	2,900	3,600 - 6,900	3,800
Dose to maximally exposed worker (millirem)	240	240	300 - 460	320
Probability of latent cancer fatality	0.000096	0.000096	0.00012 - 0.00018	0.00013
Collective dose (person-rem)	57	57	71 - 140	76
Number of latent cancer fatalities	0.023	0.023	0.028 - 0.056	0.03
Noninvolved worker				
Full-time equivalent worker years[e]	540	540	680 - 1,400	720
Dose to maximally exposed worker (millirem)	96	96	120 - 180	130
Probability of latent cancer fatality	0.000038	0.000038	0.000048 - 0.000072	0.000052
Collective dose (person-rem)	4.3	4.3	5.4 - 11	5.8
Number of latent cancer fatalities	0.0017	0.0017	0.0022 - 0.0044	0.0023
All workers[f]				
Full-time equivalent worker years	3,400	3,400	4,300 - 8,300	4,500
Collective dose (person-rem)	61	61	76 - 150	82
Number of latent cancer fatalities	0.024	0.024	0.030 - 0.06	0.033

a. Source: Exposure rates from Table F-7.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Source: Table F-42.
f. Totals might differ from sums of values due to rounding.

Table F-66. Summary of industrial hazard health and safety impacts to facility workers during closure phase.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	350	330	400 - 600	390
Lost workday cases	170	160	190 - 280	180
Fatalities	0.17	0.16	0.19 - 0.28	0.18
Noninvolved workers				
Total recordable cases of injury and illness	54	50	59 - 82	56
Lost workday cases	26	24	29 - 40	27
Fatalities	0.048	0.044	0.052 - 0.072	0.049
All workers[e]				
Total recordable cases of injury and illness	400	380	460 - 680	450
Lost workday cases	200	180	220 - 320	210
Fatalities	0.22	0.2	0.24 - 0.35	0.23

a. Sources: Tables F-61 and F-62.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-67. Summary of radiological health impacts to workers from all activities during closure phase.[a,b]

Worker group	Operating mode			
	Higher-temperature		Lower-temperature	
	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	8,000	8,000	11,000 - 18,000	11,000
Probability of latent cancer fatality	0.0032	0.0032	0.0044 - 0.0072	0.0044
Collective dose (person-rem)	520	520	660 - 1,100	700
Number of latent cancer fatalities	0.21	0.21	0.26 - 0.44	0.28
Noninvolved worker				
Dose to maximally exposed worker (millirem)	430	430	540 - 830	580
Probability of latent cancer fatality	0.00017	0.00017	0.00022 - 0.00033	0.00023
Collective dose (person-rem)	19	19	24 - 50	26
Number of latent cancer fatalities	0.0076	0.0076	0.0096 - 0.02	0.01
All workers[e]				
Collective dose (person-rem)	540	540	680 - 1,200	730
Number of latent cancer fatalities	0.22	0.22	0.27 - 0.48	0.29

a. Sources: Tables F-63, F-64, and F-65.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.3.3.5 Summary of Impacts for All Repository Phases

Tables F-68 and F-69 present the occupational and radiological impacts, respectively, to all workers from all activities performed during all phases. In each table, impacts are presented for the higher-temperature uncanistered and dual-purpose canister packaging scenarios; in addition, the range of impacts for the lower-temperature uncanistered packaging scenario is presented along with the impacts for the dual-purpose canister packaging scenario with long-term ventilation without aging.

Table F-68. Summary of industrial hazard health and safety impacts to facility workers during all phases.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved workers				
Total recordable cases of injury and illness	2,900	2,400	3,400 - 4,000	3,300
Lost workday cases	1,400	1,200	1,600 - 1,900	1,600
Fatalities	2.1	1.6	2.4 - 3.1	2.4
Noninvolved workers				
Total recordable cases of injury and illness	640	680	690 - 830	800
Lost workday cases	310	340	340 - 410	390
Fatalities	0.61	0.65	0.65 - 0.78	0.75
All workers[e]				
Total recordable cases of injury and illness	3,500	3,100	4,100 - 4,800	4,100
Lost workday cases	1,700	1,500	1,900 - 2,300	2,000
Fatalities	2.7	2.3	3.1 - 3.9	3.2

a. Sources: Tables F-12, F-52, F-59, and F-66.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

Table F-69. Summary of radiological health impacts to workers from all activities during all phases.[a,b]

	Operating mode			
	Higher-temperature		Lower-temperature	
Worker group	UC[c]	DPC[d]	UC (range)	DPC
Involved worker				
Dose to maximally exposed worker (millirem)	24,000	24,000	24,000 - 33,000	24,000
Probability of latent cancer fatality	0.0096	0.0096	0.0096 - 0.013	0.0096
Collective dose (person-rem)	14,000	9,900	16,000 - 20,000	14,000
Number of latent cancer fatalities	5.6	4.0	6.4 - 8	5.6
Noninvolved worker				
Dose to maximally exposed worker (millirem)	2,400	2,400	2,400	2,400
Probability of latent cancer fatality	0.00096	0.00096	0.00096	0.00096
Collective dose (person-rem)	270	270	330 - 410	400
Number of latent cancer fatalities	0.11	0.11	0.13 - 0.16	0.16
All workers[e]				
Collective dose (person-rem)	14,000	10,000	16,000 - 20,000	14,000
Number of latent cancer fatalities	5.6	4	6.4 - 8	5.6

a. Source: Sum of values from Tables F-11, F-53, F-60, and F-67.
b. Numbers are rounded to two significant figures.
c. UC = uncanistered packaging scenario.
d. DPC = dual-purpose canister packaging scenario.
e. Totals might differ from sums of values due to rounding.

F.4 Worker Human Health and Safety Impact Analysis for the Retrieval Contingency

Nuclear Regulatory Commission regulations state that the period for which DOE must maintain the ability to retrieve waste is at least 50 years after the start of emplacement operations [10 CFR 60.111(b)]. Although DOE does not anticipate retrieval and it is not part of the Proposed Action, the Department would maintain the ability to retrieve the waste for at least 100 years and possibly for as long as 300 years after the start of emplacement. Factors that could lead to a decision to retrieve the waste would be (1) to protect the public health and safety or the environment or (2) to recover resources from spent nuclear fuel. This EIS evaluates retrieval as a contingency action and describes potential impacts should it occur. The analysis assumes that under this contingency DOE would retrieve all the waste associated with the Proposed Action and would place it on surface storage pads pending future decisions about its ultimate disposition.

The analysis of health and safety impacts to workers divided the retrieval period into two subperiods, as follows:

- First, a construction subperiod in which DOE would (1) build the surface facilities necessary to handle and enclose retrieved waste packages in concrete storage units in preparation for placement on concrete storage pads, and (2) construct the concrete storage pads.

  No radioactive materials would be involved in the construction subperiod, so health and safety impacts would be limited to those associated with industrial hazards in the workplace. DOE expects this subperiod would last 2 to 3 years, although construction of the concrete storage pads probably would continue on an as-needed basis during most of the operations subperiod. The analysis assumed a 3-year period.

- Second, an operations subperiod during which the waste packages would be retrieved and moved to the Waste Retrieval Transfer Building. Surface facility workers would unload the waste package from the transfer vehicle and place it on a concrete base. The package and concrete base would then be enclosed in a concrete storage unit that would be placed on the concrete storage pad. The analysis assumed an 11-year period.

This section discusses the methodologies and data used to estimate human health and safety impacts resulting from the retrieval contingency. Section F.4.1 describes the methods DOE used to estimate impacts. Section F.4.2 contains tabulations of the detailed data used in the impact calculations and references to the data sources. Section F.4.3 contains detailed tabulations of the results.

F.4.1 METHODOLOGY FOR CALCULATING HUMAN HEALTH AND SAFETY IMPACTS

DOE used the methodology summarized in Section F.2.1 to estimate health and safety impacts for the retrieval contingency. This involved assembling data for the number of full-time equivalent workers for each retrieval activity. These numbers were used with statistics on the likelihood of an impact (industrial hazards), or the estimated radiological dose rate in the worker environment, to calculate health and safety impacts. The way in which the input data were combined to calculate health and safety impacts is described in more detail in Section F.2.1. Some of the input data in the retrieval impact calculations are different from those for the Proposed Action, as described in the next section.

F.4.2 DATA SOURCES AND TABULATIONS

F.4.2.1 Full-Time Equivalent Worker-Year Estimates for the Retrieval Contingency

This analysis divides the repository workforce into two groups—involved and noninvolved workers (see Section F.2 for definitions of involved and noninvolved workers).

Table F-70 lists the number of full-time equivalent work years for the two subperiods of the retrieval operation and the sources of the numbers. Each full-time equivalent worker year represents 2,000 work hours, the hours assumed to be worked in a normal work year. The full-time equivalent worker-year estimates are independent of repository operating mode.

Table F-70. Full-time equivalent worker-year estimates for retrieval.

Subperiod and worker group	Length of subperiod (years)	Full-time equivalent worker years[a]
Surface facilities, construction[b]	3	
Involved		1,300
Noninvolved		500
Surface facilities, retrieval support[c]	11	
Involved		320
Noninvolved		870
Subsurface facility retrieval operations[d]	11	
Involved		810
Noninvolved		180
Total		**4,000**

a. Numbers are rounded to two significant figures.
b. Source: DIRS 154758-Lane (2000, all).
c. Source: DIRS 152010-CRWMS M&O (2000, Table I-3, p. I-20).
d. Source: DIRS 150941-CRWMS M&O (2000, Table 6-29, p. 6-20).

F.4.2.2 Statistics on Health and Safety Impacts from Industrial Hazards in the Workplace

For the retrieval contingency, DOE used the same set of statistics on health and safety impacts from industrial hazards common to the workplace that were used for the Proposed Action (70,000 MTHM) (see Table F-4). The specific statistics that were applied to the retrieval contingency subphases are listed in Table F-71.

F.4.2.3 Estimated Radiological Exposure Rates and Times for the Retrieval Contingency

DOE used the same set of worker exposure rate data as those used for evaluating radiological worker impacts for the Proposed Action. Table F-72 presents the specific application of this data to the retrieval contingency subphases. The source of the information is also referenced. The rates used in the analysis did not take into account radioactive decay for the period between emplacement and retrieval.

Table F-71. Statistics for industrial hazard impacts for retrieval.

Subperiod and worker group	Total recordable incidents (rate per 100 FTEs)[a]	Lost workday cases (rate per 100 FTEs)[a]	Fatalities (rate per 100,000 FTEs)[a,b]
Construction, surface workers[c]			
Involved	6.1	2.9	2.9
Noninvolved	3.3	1.6	
Retrieval, surface workers[d]			
Involved	3.0	1.2	2.9
Noninvolved	3.3	1.6	
Retrieval, subsurface workers[d]			
Involved	3.0	1.2	2.9
Noninvolved	3.3	1.6	

a. FTE = full-time equivalent worker years.
b. Source: Data Set 4, Section F.2.2.
c. Source: Data Set 1, Section F.2.2.
d. Source: Data Set 3, Section F.2.2.

Table F-72. Radiological doses and exposure data used to calculate worker exposures during retrieval.[a]

Subperiod and worker group	Source of exposure	Occupancy factor for exposure rate (fraction of 8-hour workday)	Annual dose (millirem)	Source[b]
Construction				
Surface				
Involved	None			
Noninvolved	None			
Operations				
Surface				
Involved	Waste package	1.0	25	(1)
Noninvolved	Waste package	1.0	0	(1)
Subsurface				
Involved	Waste package	1.0	600	(2)
	Radon-222[c]	1.0	20	Table F-2
	Drift ambient	1.0	50	Section F.1.1.6
Noninvolved	Waste package	0.04 (0.4 for 10% of workers)	200	(3)
	Radon-222	0.4	20	Table F-2
	Drift ambient	0.4	50	Sections F.1.1.6

a. External exposures include radiation from spent nuclear fuel and high-level radioactive waste packages to surface and subsurface workers, the ambient exposure to subsurface workers from naturally occurring radiation in the drift walls, and subsurface worker exposure from inhalation of radon-222.
b. Sources:
(1) DIRS 152010-CRWMS M&O (2000, Table I-3, p. I-20).
(2) Table F-6.
(3) Table F-2; DIRS 104536-Rasmussen (1999, all).
c. Exposure rates from inhalation of radon-222 are assumed to be the same as those for the construction phase.

F.4.3 DETAILED RESULTS FOR THE RETRIEVAL CONTINGENCY

F.4.3.1 Construction Phase

F.4.3.1.1 *Human Health and Safety Impacts to Workers from Industrial Hazards*

The construction phase would entail only surface-facility activities. Table F-73 summarizes health and safety impacts to workers from industrial hazards during construction. There would be no radiological sources present during surface facility construction activities for retrieval and, hence, no radiological health and safety impacts to workers.

Table F-73. Industrial hazard health and safety impacts to workers during construction.[a,b]

Worker group	Impacts
Involved	
Total recordable cases of injury and illness	80
Lost workday cases	38
Fatalities	0.04
Noninvolved	
Total recordable cases of injury and illness	16
Lost workday cases	8
Fatalities	0.01
All workers (totals)	
Total recordable cases of injury and illness	96
Lost workday cases	46
Fatalities	0.05

a. Source: Calculated using impact rates from Table F-71.
b. Numbers are rounded to two significant figures.

F.4.3.2 Operations Period

F.4.3.2.1 *Health and Safety Impacts to Workers from Industrial Hazards*

Chapter 4, Table 4-55, summarizes health and safety impacts to workers from industrial hazards common to the workplace for the retrieval operations period. The impacts in that table consist of two components—health impacts to surface workers and health impacts to subsurface workers. Tables F-74 and F-75 list health impacts from industrial hazards during retrieval operations for these two components, surface and subsurface workers, respectively.

F.4.3.2.2 *Radiological Health and Safety Impacts to Workers*

Potential radiological health impacts to workers during the operations period of retrieval consist of the following components:

- Impacts to surface facility workers involved in handling the waste packages and placing them in concrete storage units

- Impacts to subsurface facilities workers from direct radiation emanating from the waste packages

- Impacts to subsurface workers from inhalation of radon-222 in the atmosphere of the drifts
- Impacts to subsurface workers from ambient radiation from naturally occurring radionuclides in the drift walls

Tables F-76 and F-77 list potential radiological health impacts for each of these component parts.

Table F-74. Industrial hazard health and safety impacts to surface facility workers during retrieval operations.[a,b]

Worker group	Impacts
Involved	
Total recordable cases of injury and illness	10
Lost workday cases	4
Fatalities	0.009
Noninvolved	
Total recordable cases of injury and illness	29
Lost workday cases	14
Fatalities	0.03
All workers (totals)[c]	
Total recordable cases of injury and illness	39
Lost workday cases	18
Fatalities	0.039

a. Source: Impact rates from Table F-71.
b. Numbers are rounded to two significant figures.
c. Totals might differ from sums of values due to rounding.

Table F-75. Industrial hazard health and safety impacts to subsurface facility workers during retrieval operations.[a,b]

Worker group	Impacts
Involved	
Total recordable cases of injury and illness	24
Lost workday cases	11
Fatalities	0.02
Noninvolved	
Total recordable cases of injury and illness	6
Lost workday cases	3
Fatalities	0.01
All workers (totals)[c]	
Total recordable cases of injury and illness	30
Lost workday cases	14
Fatalities	0.03

a. Source: Impact rates from Table F-71.
b. Numbers are rounded to two significant figures.
c. Totals might differ from sums of values due to rounding.

Table F-76. Radiological health impacts to surface facility workers from waste handling during retrieval operations.[a]

Worker group	Impacts
Involved	
Maximally exposed individual dose (millirem)	280
Latent cancer fatality probability for maximally exposed individual	0.0001
Collective dose (person-rem)	8
Latent cancer fatality incidence for overall worker group	0.003
Noninvolved	
Maximally exposed individual dose (millirem)	0
Latent cancer fatality probability for maximally exposed individual	0
Collective dose (person-rem)	0
Latent cancer fatality incidence for overall worker group	0
All workers (totals)[b]	
Collective dose (person-rem)	8
Latent cancer fatality	0.003

a. Source: Exposure rate data from Table F-72.
b. Totals might differ from sums due to rounding.

Table F-77. Components of radiological health impacts to subsurface workers during retrieval operations.[a]

	Source of exposure			
Worker group	Waste packages	Ambient	Radon-222 inhalation	Total[b]
Involved				
Maximally exposed individual dose (millirem)	5,200	550	1,400	5,900
Latent cancer fatality probability for maximally exposed individual	0.002	0.0002	0.0009	0.002
Collective dose (person-rem)	66	41	16	120
Latent cancer fatality incidence for overall worker group	0.08	0.02	0.04	0.05
Noninvolved				
Maximally exposed individual dose (millirem)	88	220	130	440
Latent cancer fatality probability for maximally exposed individual	0.00004	0.00009	0.00005	0.0002
Collective dose (person-rem)	1	4	1	4
Latent cancer fatality incidence for overall worker group	0.0004	0.001	0.0006	0.002
All workers (totals)[c]				
Collective dose (person-rem)	67	45	17	130
Latent cancer fatality incidence for overall worker group	0.08	0.02	0.04	0.05

a. Source: Exposure data from Table F-72.
b. Totals might differ from sums due to rounding.
c. Source: FTE values from Table F-70.

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Appendix G

Air Quality

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APPENDIX G. AIR QUALITY

Potential releases of nonradiological and radiological pollutants associated with the construction, operation and monitoring, and closure of the proposed Yucca Mountain Repository could affect the air quality in the surrounding region. This appendix discusses the methods and additional data and intermediate results that the U.S. Department of Energy (DOE) used to estimate impacts from potential releases to air. Results for the Proposed Action are presented in Chapter 4, Section 4.1.2, and in Chapter 8, Section 8.2.2 for Inventory Modules 1 and 2.

Nonradiological pollutants can be categorized as hazardous and toxic air pollutants, criteria pollutants, or other substances of particular interest. Repository activities would cause the release of no or very small quantities of hazardous and toxic pollutants; therefore, these pollutants were not considered in the analysis. Concentrations of six criteria pollutants are regulated under the National Ambient Air Quality Standards (40 CFR Part 50) established by the Clean Air Act. This analysis evaluated releases and potential impacts of four of these pollutants—carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter with an aerodynamic diameter of 10 micrometers or less (PM_{10})—quantitatively. It also considered the two other criteria pollutants—lead and ozone—and particulate matter with an aerodynamic diameter of 2.5 micrometers or less ($PM_{2.5}$), a new limit, which has not yet been implemented. In addition, this analysis considers potential releases to air of cristobalite, a form of crystalline silica that can cause silicosis and is a potential carcinogen. These pollutants could be released during all project phases. Section G.1 describes the methods DOE used to calculate impacts from releases of criteria pollutants and cristobalite.

Radionuclides that repository-related activities could release to the atmosphere include the noble gas krypton-85 from spent nuclear fuel handling during the operation and monitoring phase, and naturally occurring radon-222 and its decay products from ventilation of the subsurface facility during all project phases. Other radionuclides would not be released or would be released in such small quantities they would result in very small impacts to air quality. Such radionuclides are not discussed further in this appendix. Section G.2 describes the methods DOE used to calculate impacts of radionuclide releases.

G.1 Nonradiological Air Quality

This section describes the methods DOE used to analyze potential impacts to air quality at the proposed Yucca Mountain Repository from releases of nonradiological air pollutants during the construction, operation and monitoring, and closure phases, and a retrieval scenario. It also describes intermediate results for various repository activities. Table G-1 lists the six criteria pollutants regulated under the National Ambient Air Quality Standards or the Nevada Administrative Code along with their regulatory limits and the periods over which pollutant concentrations are averaged. The criteria pollutants addressed quantitatively in this section are nitrogen dioxide, sulfur dioxide, particulate matter 10 micrometers or less in aerodynamic diameter (PM_{10}), and carbon monoxide. No sources of airborne lead would occur at the repository, so evaluations and results are not presented. Particulate matter 2.5 micrometers or less in aerodynamic diameter ($PM_{2.5}$) and ozone are discussed below, as is cristobalite, a mineral occurring naturally in the subsurface rock at Yucca Mountain.

The purpose of the ozone standard is to control the ambient concentration of ground-level ozone, not naturally occurring ozone in the upper atmosphere. Ozone is not emitted directly into the air; rather, it is formed when volatile organic compounds react in the presence of sunlight. Nitrogen dioxides are also important precursors to ozone. Small quantities of volatile organic compounds would be released from repository activities; the peak annual release would be about 700 kilograms (1,500 pounds) (DIRS 152010-CRWMS M&O 2000, Table 6-2, p. 52). Because Yucca Mountain is in an attainment area for ozone, the analysis compared the estimated annual release to the Prevention of Significant Deterioration

Table G-1. Criteria pollutants and regulatory limits.

Pollutant	Period	Regulatory limit[a] Parts per million	Micrograms per cubic meter
Nitrogen dioxide	Annual	0.053	100
Sulfur dioxide	Annual	0.03	80
	24-hour	0.14	365
	3-hour	0.50	1,300
Carbon monoxide	8-hour	9	10,000
	1-hour	35	40,000
PM_{10}	Annual		50
	24-hour		150
$PM_{2.5}$[b]	Annual		15
	24-hour		65
Ozone	8-hour	0.08	157
	1-hour	0.12	235
Lead	Quarterly		1.5

a. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391. Not all limits are provided in parts per million.

b. Standard not yet implemented.

of Air Quality emission threshold for volatile organic compounds from stationary sources (40 CFR 52.21). The volatile organic compound emission threshold is 35,000 kilograms (77,000 pounds) per year, so the peak annual release from the repository would be well below this level. Accordingly, the analysis did not address volatile organic compounds and ozone further, although this does not preclude future, more detailed analyses if estimates of volatile organic compound emissions change.

The U.S. Environmental Protection Agency revised the primary and secondary standards for particulate matter in 1997 (62 *FR* 38652, July 18, 1997), establishing annual and 24-hour $PM_{2.5}$ standards at 15 micrograms per cubic meter and 65 micrograms per cubic meter, respectively. Primary standards set limits to protect public health, including the health of "sensitive" populations. Secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Because the new particulate standard will regulate $PM_{2.5}$ for the first time, the agency has allowed 5 years for the creation of a national monitoring network and the analysis of collected data to help develop state implementation plans. The new $PM_{2.5}$ standards have not been implemented and the imposition of local area controls will not be required until 2005. By definition, $PM_{2.5}$ levels can be no more than, and in the real world are always substantially less than, PM_{10} levels. In general, $PM_{2.5}$ levels would be approximately one-third of the PM_{10} levels. As the analysis for PM_{10} shows, even the maximum PM_{10} levels that could be generated by the Proposed Action are substantially below the $PM_{2.5}$ standards. Thus, although no detailed $PM_{2.5}$ analysis has been conducted, the PM_{10} analysis can be regarded as a surrogate for a $PM_{2.5}$ analysis and illustrates that potential $PM_{2.5}$ levels would be well below applicable regulatory standards.

Cristobalite, one of several naturally occurring crystalline forms of silica (silicon dioxide), is a major mineral constituent of Yucca Mountain tuffs (DIRS 104523-CRWMS M&O 1999, p. 4-81). Prolonged high exposure to crystalline silica can cause silicosis, a disease characterized by scarring of lung tissue. An increased cancer risk to humans who already have developed adverse noncancer effects from silicosis has been shown, but the cancer risk to otherwise healthy individuals is not clear (DIRS 103243-EPA 1996, p. 1-5). Cristobalite is principally a concern for involved workers because it could be inhaled during subsurface excavation operations. Appendix F, Section F.1.2, contains additional information on crystalline silica.

While there are no limits for exposure of the general public to cristobalite, there are limits to workers for exposure (29 CFR 1910.1000). Therefore, this analysis used a comparative benchmark of 10 micrograms per cubic meter, based on a cumulative lifetime exposure of 1,000 micrograms per cubic meter multiplied by years (that is, the average annual exposure concentration times the number of years exposed). At this level, an Environmental Protection Agency health assessment (DIRS 103243-EPA 1996, pp. 1-5 and 7-5) states that there is a less than 1-percent chance of silicosis. Over a 70-year lifetime, this cumulative exposure benchmark would correspond to an annual average exposure concentration of about 14 micrograms per cubic meter, which was rounded down to 10 micrograms per cubic meter to establish the benchmark.

Cristobalite would be emitted from the subsurface in exhaust ventilation air during excavation operations and would be released as fugitive dust from the excavated rock pile, so members of the public and noninvolved workers could be exposed. Fugitive dust from the excavated rock pile would be the largest potential source of cristobalite exposure to the public. The analysis assumed that 28 percent of the fugitive dust released from this rock pile and from subsurface excavation would be cristobalite, reflecting the cristobalite content of the parent rock, which ranges from 18 to 28 percent (DIRS 104523-CRWMS M&O 1999, p. 4-81). Using the parent rock percentage probably overestimated the airborne cristobalite concentration, because studies of both ambient and occupational airborne crystalline silica have shown that most of this airborne material is coarse and not respirable and that larger particles deposit rapidly on the surface (DIRS 103243-EPA 1996, p. 3-26).

G.1.1 COMPUTER MODELING AND ANALYSIS

DOE used the Industrial Source Complex computer program to estimate the annual and short-term (24-hour or less) air quality impacts at the proposed Yucca Mountain Repository. The Department has used this program in recent EISs (DIRS 101802-DOE 1995, all; DIRS 101814-DOE 1997, all; DIRS 101816-DOE 1997, all) to estimate nonradiological air quality impacts. The program contains both a short-term model (which uses hourly meteorological data) and a long-term model (which uses joint frequency meteorological data). The program uses steady-state Gaussian plume models to estimate pollutant concentrations from a variety of sources associated with industrial complexes (DIRS 103242-EPA 1995, all). This modeling approach assumes that (1) the time-averaged pollutant concentration profiles at any distance downwind of the release point may be represented by a Gaussian (normal) distribution in both the horizontal and vertical directions; and (2) the meteorological conditions are constant (persistent) over the time of transport from source to receptor. The Industrial Source Complex program is appropriate for either flat or rolling terrain, and for either urban or rural environments. The Environmental Protection Agency has approved this program for specific regulatory applications. Input requirements for the program include source configuration and pollutant emission parameters. The short-term model was used in this analysis to estimate all nonradiological air quality impacts and uses hourly meteorological data that include wind speed, wind direction, and stability class to compute pollutant transport and dispersion.

Because the short-term pollutant concentrations were based on annual usage or release parameters, conversion of annual parameter values to short-term values depended on the duration of the activity. Many of the repository activities were assumed to have a schedule of 250 working days per year, so the daily release would be the annual value divided by 250.

In many cases, site- or activity-specific information was not available for estimating pollutant emissions at the Yucca Mountain site. In these cases, generic information was used and conservative assumptions were made that tended to overestimate actual air concentrations.

As noted in Section G.1, the total nonradiological air quality impacts are described in Chapter 4, Section 4.1.2, for the Proposed Action and in Chapter 8, Section 8.2.2, for the inventory modules. These impacts are the sum of air quality impacts from individual sources and activities that take place during each of the project phases and that are discussed later in this section (for example, dust emissions from the concrete batch facility during the construction phase). The maximum air quality impact (that is, air concentration) resulting from individual sources or activities could occur at different land withdrawal area boundary locations depending on the release period and the regulatory averaging time (see Section G.1.3). These maximums generally occur in a westerly or southerly direction. The total nonradiological air quality impacts presented in Sections 4.1.2 and 8.2.2 are the sum of the calculated maximum concentrations regardless of direction. Therefore, the values presented would be larger than the actual sum of the concentrations for a particular distance and direction. This approach was selected to simplify the presentation of air quality results.

G.1.2 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS

The location of the public maximally exposed individual was determined by calculating the maximum ground-level pollutant concentrations. Because unrestricted public access would be limited to the site boundary, the analysis assumed that a hypothetical individual would be present at one point on the site boundary during the entire averaging time of the regulatory limit (Table G-1).

Table G-2 lists the distances from the North and South Portals to the land withdrawal area boundary where maximally exposed individual locations were evaluated. The table does not list all directions because the land withdrawal area boundaries would not be accessible to members of the public in some directions (restricted access areas of the Nevada Test Site and Nellis Air Force Range). The distance to the nearest unrestricted public access in these directions would be so large that there would be no air quality impacts. For the east to south-southeast directions, the distances to the land withdrawal area boundary would be large, but the terrain is such that plumes traveling in these directions tend to enter Fortymile Wash and turn south. The southern land withdrawal area boundary would be the location of a maximally exposed individual with long-term (1-year) unrestricted access, such as a resident. The short-term (1 to 24 hours) maximally exposed individual location would be the western land withdrawal area boundary, where an individual such as a hiker or hunter could be located. No long-term access (that is, residency) could occur at this location on government-owned land. The access periods evaluated are based on the exposure periods listed in Table G-1.

Table G-2. Distance to the nearest point of unrestricted public access (kilometers).[a,b,c]

Direction	From North Portal	From South Portal
Northwest	14	15
West-northwest	12	12
West	11	11
West-southwest	14	12
Southwest	18	16
South-southwest	23	19
South	21	18
South-southeast	21	19
Southeast	22	24

a. Source: Derived from (DIRS 104493-YMP 1997, all and DIRS 153849-DOE 2001, p. l-21)
b. Numbers are rounded to two significant figures.
c. To convert kilometers to miles, multiply by 0.62137.

G.1.3 METEOROLOGICAL DATA AND REFERENCE CONCENTRATIONS

DOE estimated the concentrations of criteria pollutants in the region of the repository by using the Industrial Source Complex program and site-specific meteorological data for 1993 to 1997 from air quality and meteorology monitoring Site 1 (DIRS 102877-CRWMS M&O 1999, electronic addendum). Site 1 is less than 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location.

Similar topographic exposure leads to similar prevailing northerly and southerly winds at both locations. DOE used Site 1 data because an analysis of the data collected at all the sites showed that site to be most representative of the surface facilities (DIRS 102877-CRWMS M&O 1999, p. 7). Wind speed data are from the 10-meter (33-foot) level, as are atmospheric stability data, using the night-adjusted sigma-theta method (DIRS 101822-EPA 1987, pp. 6-20 to 6-32). Mixing height measurements were not available for Yucca Mountain so the analysis assumed a mixing height of approximately 140 meters (470 feet), which is one-tenth of the 1,420 meters (4,700 feet) mixing-layer depth for Desert Rock, Nevada. Desert Rock is the nearest upper air meteorological station, about 44 kilometers (27 miles) east-southeast near Mercury, Nevada. The average mixing height at Desert Rock was divided by 10 to simulate the mixing height during very stable conditions, which is when the highest concentrations from a ground-level source would normally occur. All nonradiological pollutant releases were assumed to come from ground-level point sources. Both of these conservative assumptions, made because of a lack of site-specific information, tend to overestimate actual air concentrations. Fugitive dust emissions could be modeled as an area source, but the distance from the source to the exposure location would be large [more than 10 kilometers (6 miles)] so a point source provides a good approximation. Some sources would have plume rise, such as boiler emissions, but this was not considered because there is inadequate information to characterize the rise.

The analysis estimated unit release concentrations at the land withdrawal area boundary points of maximum exposure for ground-level point-source releases. The concentrations were based on release rates of 1 gram (0.04 ounce) per second for each of the five regulatory limit averaging times (annual, 24-hour, 8-hour, 3-hour, or 1-hour). Various activities at the Yucca Mountain site could result in pollutants being released over four different periods in a 24-hour day [continuously, 8-hour, 12-hour (two 6-hour periods), or 3-hour]. Eleven combinations of release periods and regulatory limit averaging times would be applicable to activities at the Yucca Mountain site.

The analysis assumed that the 8-hour pollutant releases would occur from 8 a.m. to 4 p.m. and to be zero for all other hours of the day. Similarly, it assumed that the 3-hour releases would occur from 9 a.m. to 12 p.m. and to be zero for all other hours. The 12-hour release would occur over two 6-hour periods, assumed to be from 9 a.m. to 3 p.m. and from 5 p.m. to 11 p.m.; other hours would have zero release. Continuous releases would occur throughout the 24-hour day. The estimates of all annual-average concentrations assumed the releases were continuous over the year.

Table G-3 lists the maximum unit release concentrations for the 11 combinations of the Yucca Mountain site-specific release periods and regulatory limit averaging times. The analysis estimated the unit concentrations and directions using the meteorological data during a single year from 1993 through 1997 (DIRS 102877-CRWMS M&O 1999, electronic addendum) that would result in the highest unit concentration. For all years, the unit release concentrations for a particular averaging time are within a factor of 2 of each other. Table G-3 lists the 24-hour averaged concentration for the 3- and 12-hour release scenarios because the activities associated with these scenarios would only release PM_{10}, which has annual and 24-hour regulatory limits. The estimated concentration at the point of exposure was calculated by multiplying the estimated source release rate (presented for each source in the following sections) by the maximum unit release concentration for that averaging period.

Table G-3. Unit release concentrations (micrograms per cubic meter based on a release of 1 gram per second) and direction to maximally exposed individual location for 11 combinations of 4 release periods and 5 regulatory limit averaging times.[a]

	Direction from South Portal Development area	Unit release concentration	Direction from North Portal Operations Area	Unit release concentration
Continuous release – annual average concentration (1995)[b]				
	South-southeast	0.12	South-southeast	0.099
Continuous release – 24-hour average concentration (1993)				
	Southeast	1.0	West	0.95
Continuous release – 8-hour average concentration (1995)				
	Southeast	3.0	Southeast	2.5
Continuous release – 3-hour average concentration (1995)				
	West	6.1	West	6.1
Continuous release – 1-hour average concentration (1995)				
	West	18	West	18
8-hour release (8 a.m. to 4 p.m.) – 24-hour average concentration (1997)				
	West-southwest	0.19	West-northwest	0.18
8-hour release (8 a.m. to 4 p.m.) – 8-hour average concentration (1997)				
	West-southwest	0.57	West-northwest	0.52
8-hour release (8 a.m. to 4 p.m.) – 3-hour average concentration (1997)				
	West-southwest	1.5	West-northwest	1.4
8-hour release (8 a.m. to 4 p.m.) – 1-hour average concentration (1997)				
	West-northwest	3.3	West-northwest	3.3
12-hour release (9 a.m. to 3 p.m. and 5 p.m. to 11 p.m.) – 24-hour average concentration (1997)				
	West	0.95	West	0.95
3-hour release (9 a.m. to 12 p.m.) – 24-hour average concentration (1997)				
	West-northwest	0.17	West-northwest	0.17

a. Numbers are rounded to two significant figures.
b. Number in parentheses is the year from 1993 through 1997 for which meteorological data would result in the highest unit concentration.

G.1.4 CONSTRUCTION PHASE

This section describes the method used to estimate air quality impacts during the 5-year construction phase. DOE would complete the surface facilities during the construction phase, as well as sufficient excavation of the subsurface to support initial emplacement activities.

This analysis used calculations of the pollutant concentrations from various construction activities to determine air quality impacts. To calculate these impacts, estimated pollutant emission rates discussed in this section were multiplied by the unit release concentration (see Section G.1.3). This produced the pollutant concentration for comparison to regulatory limits. Short-term pollutant emission rates and concentrations were estimated using the method described in Section G.1.1.

The principal emission sources of particulates would be fugitive dust from construction activities on the surface, excavation of rock from the repository, storage of material on the excavated rock pile, and dust emissions from the concrete batch facility. The principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion in trucks, cranes, and graders and emissions from a boiler in the South Portal Development Area. Nitrogen dioxide, sulfur dioxide, and carbon monoxide would also be emitted during maintenance of the excavated rock pile. The following sections describe these sources in more detail.

G.1.4.1 Fugitive Dust Emissions from Surface Construction

Fugitive dust would be generated during such construction activities as earth moving and truck traffic. All surface construction activities and associated fugitive dust releases were assumed to occur during 250 working days per year with one 8-hour shift per day. The preferred method suggested by the Environmental Protection Agency would be to break the construction activities into component activities (for example, earth moving, truck traffic) and calculate the emissions for each component. However, detailed information was not available for the construction phase, so a generic, conservative approach was taken. The release rate of total suspended particulates (particulates with aerodynamic diameters of 30 micrometers or less) was estimated as 0.27 kilogram per square meter (1.2 tons per acre) per month (DIRS 101824-EPA 1995, pp. 13.2.3-1 to 13.2.3-7). This estimated emission rate for total suspended particulates was based on measurements made during the construction of apartments and shopping centers.

The amount of PM_{10} (the pollutant of interest) emitted from the construction of the Yucca Mountain Repository probably would be less than 0.27 kilogram per square meter (1.2 tons per acre) per month because many of the particulates suspended during construction would be at the larger end of the 30-micrometer range and would tend to settle rapidly (DIRS 102180-Seinfeld 1986, pp. 26 to 31). Experiments on dust suspension due to construction found that at 50 meters (160 feet) downwind of the source, a maximum of 30 percent of the remaining suspended particulates at respirable height were in the PM_{10} range (DIRS 103678-Midwest Research Institute 1988, pp. 22 to 26). Based on this factor, only 30 percent of the 0.27 kilogram per square meter per month of total suspended particulates, or 0.081 kilogram per square meter (0.36 ton per acre) per month, would be emitted as PM_{10} from construction activities. Because the default emission rate was based on continuous emissions over 30 days, the daily PM_{10} emission rate would be 0.0027 kilogram per square meter (0.012 ton per acre) per day, or 0.00011 kilogram per square meter (0.00050 ton per acre) per hour. Dust suppression activities would reduce PM_{10} emissions; however, the analysis took no credit for normal dust suppression activities.

The estimation of the annual and 24-hour average PM_{10} emission rates required an estimate of the size of the area to be disturbed along with the unit area emission rate [0.00011 kilogram per square meter (0.00050 ton per acre) per hour] times 8 hours of construction per day. The analysis estimated that 20 percent of the total disturbed land area would be actively involved in construction activities at any given time. This was based on the total disturbed area at the end of the construction period divided by the number of years construction activities would last. Table G-4 lists the total areas of disturbance at various repository operation areas. The analysis assumed that the entire land area required for excavated rock storage (for both the construction phase and operation period) would be disturbed by excavated rock storage preparation activities, although only a portion of it would be used during the construction phase. Table G-5 lists fugitive dust emissions from surface construction; Table G-6 lists estimated air quality impacts from fugitive dust as the pollutant concentration in air and as the percent of the applicable regulatory limit.

Fugitive dust from construction would produce small offsite PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be as high as 1.4 percent and about 3.3 percent, respectively, of the regulatory limit for the lower-temperature repository operating mode. The differences between the operating modes would be small; the lower-temperature repository operating mode would have the larger impacts due mainly to the area required for ventilation shafts, excavated rock storage, and aging pad construction, where used.

For Modules 1 and 2, the same technique was used as for the Proposed Action, but the amount of land disturbed would be larger than for the Proposed Action because of the need for more ventilation shafts and excavated rock storage. The increase in disturbed land area would increase the estimated air quality impacts. Higher-temperature repository operating mode impacts would be 1.2 percent (annual) and

2.8 percent (24-hour) of the regulatory limit. Lower-temperature repository operating mode impacts would be 1.2 to 1.7 percent (annual) and 2.9 to 4 percent (24-hour) of the regulatory limit.

Table G-4. Land area (square kilometers)[a] disturbed during the construction phase.[b]

Operations area	Operating mode: Higher-temperature	Operating mode: Lower-temperature
North Portal and roads	0.62	0.62
South Portal	0.15	0.15
Ventilation shafts and access roads	0.84	1 - 1.4
Total excavated rock storage	0.87	0.87 - 1.5
Landfill	0.04	0.04 - 0.061
Solar power generating station	0.22	0.22
Concrete batch plant	0.061	0.061
Concrete pads for aging	NA[c]	0 or 0.47[d]
Totals[e]	***2.8***	***3 - 4.5***
Area disturbed per year	0.55	0.6 - 0.83

a. To convert square kilometers to acres, multiply by 247.1.
b. Sources: DIRS 152010-CRWMS M&O (2000, p. 52); DIRS 150941-CRWMS M&O (2000, pp. 4-9 and 6-27); DIRS 150941-CRWMS M&O (2000, p. 1); DIRS 155515-Williams (2001, Part 1, pp. 27 and 29; Part 2, p. 18); DIRS 155516-Williams (2001, Item 1.5); DIRS 153882-Griffith (2001, p. 8).
c. NA = not applicable.
d. Applicable only for aging.
e. Numbers are rounded to two significant figures; therefore, totals might differ from sums of values.

Table G-5. Fugitive dust releases from surface construction (PM_{10}).[a]

Operating mode	Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	120,000	3.9
	24-hour	490	17[d]
Lower-temperature[e]	Annual	130,000 - 190,000	4.2 - 5.9
	24-hour	530 - 740	18 - 26[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.
e. Range of values for lower-temperature operating mode.

Table G-6. Estimated fugitive dust air quality impacts (micrograms per cubic meter) from surface construction (PM_{10}).[a]

Operating mode	Period	Maximum concentration	Regulatory limit	Percent of limit
Higher-temperature	Annual	0.47	50	0.95
	24-hour	3.3	150	2.2
Lower-temperature	Annual	0.51 - 0.71	50	1 - 1.4
	24-hour	3.5 - 4.9	150	2.4 - 3.3

a. Numbers are rounded to two significant figures.

G.1.4.2 Fugitive Dust from Subsurface Excavation

Fugitive dust would be released during the excavation of rock from the repository. Subsurface excavation activities would take place 250 days per year in three 8-hour shifts per day. Excavation would generate dust in the tunnels, and some of the dust would be emitted to the surface atmosphere through the ventilation system. DOE estimated the amount of dust that would be emitted by the ventilation system by using engineering judgment and best available information (DIRS 104494-CRWMS M&O 1998, p. 37).

Table G-7 lists the release rates of PM_{10} for excavation activities. Table G-8 lists estimated air quality impacts from fugitive dust as pollutant concentration in air and percentage of regulatory limit.

Table G-7. Fugitive dust releases from excavation activities (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	920	0.029
24-hour	3.7	0.043[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 24-hour release period.

Table G-8. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from excavation activities.

Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
PM_{10}			
Annual	0.0035	50	0.0070
24-hour	0.044	150	0.029
Cristobalite			
Annual	0.0010	10[b]	0.010

a. Numbers are rounded to two significant figures.
b. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from excavation operations would produce small offsite PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be much less than 1 percent of the regulatory standards. The highest estimated annual and 24-hour excavation rates, and hence the highest estimated fugitive dust concentrations, would be the same for all operating modes.

Dust generated during excavation would contain cristobalite, a naturally occurring form of crystalline silica discussed in Section G.1. The analysis estimated the amount of cristobalite released by multiplying the amount of dust released annually (shown in Table G-7) by the percentage of cristobalite in the parent rock (28 percent). Table G-8 also lists the potential air quality impacts for releases of cristobalite from excavation of the repository. Because there are no public exposure limits for cristobalite, the annual average concentration was compared to a derived benchmark level for the prevention of silicosis, as discussed in Section G.1. The offsite cristobalite concentration would be about 0.01 percent of this benchmark.

The air quality impacts from fugitive dust emissions from excavation operations during the construction phase would be the same for Modules 1 and 2 as for the Proposed Action.

G.1.4.3 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the surface excavated rock pile would generate fugitive dust. Dust would be released during the unloading of the excavated rock and subsequent smoothing of the excavated rock pile, as well as by wind erosion of the material. DOE used the total suspended particulate emission for active storage piles to estimate fugitive dust emission (DIRS 103676-Cowherd, Muleski, and Kinsey 1988, pp. 4-17 to 4-37). The equation is:

$$E = 1.9 \times (s \div 1.5) \times [(365 - p) \div 235] \times (f \div 15)$$

where E = total suspended particulate emission factor (kilogram per day per hectare [1 hectare = 0.01 square kilometer = 2.5 acres])
s = silt content of aggregate (percent)
p = number of days per year with 0.25 millimeter or more of precipitation
f = percentage of time wind speed exceeds 5.4 meters per second (12 miles per hour) at pile height

For this analysis, *s* is equal to 4 percent, a conservative default value based on the average silt content of limestone quarrying material (DIRS 101824-EPA 1995, p. 13.2.4-2), *p* is 37.75 (DIRS 104497-Fosmire 1999, all) and *f* is 16.5 (calculated from meteorological data used in the Industrial Source Complex model). Thus, *E* is equal to 7.8 kilograms of total particulates per day per hectare (6.9 pounds per day per acre). Only about 50 percent of the total particulates would be PM_{10} (DIRS 103676-Cowherd, Muleski, and Kinsey 1988, pp. 4-17 to 4-37); therefore, the emission rate for PM_{10} would be 3.9 kilograms per day per hectare (3.5 pounds per day per acre).

The analysis estimated fugitive dust from disposal and storage using the size of the area actively involved in storage and maintenance. Only a portion of the excavated rock pile would be actively disturbed by the unloading of excavated rock and the subsequent contouring of the pile, and only that portion would be an active source of fugitive dust. The analysis assumed that the rest of the excavated rock pile would be stabilized by either natural processes or DOE stabilization measures and would release small amounts of dust. Dust suppression measures applied to the active area of the pile would reduce the calculated releases.

DOE based its estimate of the size of the active portion of the excavated rock pile on the amount of material it would store there each year (see Table G-9). The volume of rock placed on the excavated rock pile from excavation activities during the construction phase (DIRS 150941-CRWMS M&O 2000, p. 6-6; DIRS 155515-Williams 2001, Part 2, p. 12; Part 2, p. 10) was divided by the height of the storage pile. The average height of the excavated rock pile would be about 6 meters (20 feet) for the higher-temperature operating mode and about 8 meters high (26 feet) for the lower-temperature operating mode. The pile heights for Inventory Modules 1 and 2 would also be 6 meters for the higher-temperature operating mode and 8 to 9 meters for the lower-temperature operating mode. The active area of the excavated rock pile was estimated using the total area of the rock pile at the end of the construction phase divided by five years of construction, with this quantity then multiplied by two (DIRS 104505-Fosmire 1999, all).

Table G-9. Characteristics of excavated rock pile during the construction phase.[a,b]

Operating mode	Rock pile area (square kilometers)[c]	Pile height (meters)	Average annual active area (square kilometers)
Higher-temperature	0.27	6	0.11
Lower-temperature	0.26 - 0.28	8	0.10 - 0.11

a. Numbers are rounded to two significant figures.
b. The construction phase would last 5 years. Subsurface excavation and rock pile activities would continue during the operation and monitoring phase (see Section G.1.5).
c. To convert square kilometers to square miles, multiply by 0.3861.

Table G-10 lists the fugitive dust release rate from disposal and storage of the excavated rock pile for the operating modes. Table G-11 lists the air quality impacts from fugitive dust as pollutant concentration and percent of regulatory limit.

Fugitive dust emissions from the excavated rock pile during the construction phase would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards.

Table G-10. Fugitive dust released from the excavated rock pile during the construction phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	16,000	0.49
	24-hour	42	0.49[d]
Lower-temperature	Annual	15,000 - 16,000	0.47 - 0.51
	24-hour	41 - 44	0.47 - 0.51[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a continuous release.

Table G-11 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.21 percent or less of the benchmark level discussed in Section G.1.

Table G-11. Fugitive dust (PM_{10}) and cristobalite air quality impacts (micrograms per cubic meter) from the excavated rock pile during the construction phase.

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.059	50	0.12
	24-hour	0.50	150	0.34
Lower-temperature	Annual	0.057 - 0.062	50	0.11 - 0.12
	24-hour	0.48 - 0.53	150	0.32 - 0.35
Cristobalite				
Higher-temperature	Annual	0.017	10[c]	0.17
Lower-temperature	Annual	0.016 - 0.017	10[c]	0.16 - 0.17

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there are no regulatory limits for cristobalite other than worker exposure limits. See Section G.1.

For Modules 1 and 2, the volume of rock excavated during the construction phase would be the same as that excavated for the Proposed Action (DIRS 152010-CRWMS M&O 2000, p. 6-6; DIRS 155515-Williams 2001, Part 1, p. 12; and Part 2, p. 10). The estimated air quality impacts would be identical for the Proposed Action and for Modules 1 and 2.

G.1.4.4 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and tunnel liners would emit dust. This facility would run 3 hours a day and would produce 100 cubic meters (130 cubic yards) of concrete per hour of operation (DIRS 104523-CRWMS M&O 1999, pp. 4-4 and 4-5). It would operate 250 days per year. Table G-12 lists emission factor estimates for the concrete batch facility (DIRS 101824-EPA 1995, pp. 11.12-1 to 11.12-5). About 0.76 cubic meter (1 cubic yard) of typical concrete weighs 1,800 kilograms (4,000 pounds) (DIRS 101824-EPA 1995, p. 11.12-3). The size of the aggregate storage pile for the concrete batch facility would be 800 square meters (0.2 acre) (DIRS 104523-CRWMS M&O 1999, pp. 4-4 and 4-5).

Table G-12. Dust release rates for the concrete batch facility (kilograms per 1,000 kilograms of concrete).[a,b]

Source/activity	Emission rate
Sand and aggregate transfer to elevated bin	0.014
Cement unloading to elevated storage silo	0.13
Weight hopper loading	0.01
Mixer loading	0.02
Wind erosion from aggregate storage	3.9 kilograms per hectare[c] per day

a. Source: DIRS 101824-EPA (1995, p. 11.12-3).
b. To convert kilograms to pounds, multiply by 2.2046.
c. 3.9 kilograms per hectare = about 21 pounds per acre.

Table G-13 lists the dust release rates of the concrete batch facility. Table G-14 lists estimated potential air quality impacts as the estimated pollutant concentration and percent of regulatory limit.

Table G-13. Dust release rates for the concrete batch facility during the construction phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	36,000	1.1
	24-hour	140	13[d]
Lower-temperature	Annual	36,000 - 46,000	1.1 - 1.5
	24-hour	140 - 180	13 - 17 [d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3.5- to 4.5- hour release period.

Table G-14. Particulate matter (PM_{10}) air quality impacts (micrograms per cubic meter) from the concrete batch facility during the construction phase.

Operating mode	Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
Higher-temperature	Annual	0.11	50	0.23
	24-hour	2.2	150	1.5
Lower-temperature	Annual	0.11 - 0.15	50	0.23 - 0.29
	24-hour	2.2 - 2.8	150	1.5 - 1.9

a. Numbers are rounded to two significant figures.

Dust emissions from the concrete batch facility during the operation and monitoring phase would produce small offsite PM_{10} concentrations. The annual and 24-hour averaged concentrations of PM_{10} would be less than 1 percent and about 2 percent of the regulatory standards, respectively.

For Modules 1 and 2, the air quality impacts from the concrete batch facility during the construction phase would be the same as for the Proposed Action.

G.1.4.5 Exhaust Emissions from Construction Equipment

Diesel- and gasoline-powered equipment would emit all four criteria pollutants during the construction phase. DIRS 103679-EPA (1991, pp. II-7-1 to II-7-7) provided pollutant emission rate estimates for heavy-duty equipment. This analysis assumed construction equipment would emit the average of the EPA reference emission rates. Emission rates from construction equipment could decrease significantly in the future. Legislation signed in early 2001 would create year 2007 emission standards that would reduce diesel vehicle emissions of particulate matter (90-percent reduction), nitrogen dioxide (95-percent reduction), and sulfur dioxide (97-percent reduction) (DIRS 155098-EPA 2000, all). Table G-15 lists the current emission rates for this equipment.

Table G-15. Pollutant emission rates (kilograms[a] per 1,000 liters[b] of fuel) for construction equipment.[c]

Pollutant	Estimated emission	
	Diesel	Gasoline
arbon monoxide	15	450
itrogen dioxide	39	13
M_{10}	3.5	0.86
ulfur dioxide	3.7	0.63

a. To convert kilograms to pounds, multiply by 2.2046.
b. To convert liters to gallons, multiply by 0.26418.
c. Source: Average of rates from DIRS 103679-EPA (1991, pp. II-7-1 to II-7-7).

Table G-16 lists the estimated average amount of fuel consumed per year during the construction phase. The fuel for the South Portal Development Area would include fuel consumed during maintenance of the excavated rock pile.

Table G-16. Amount of fuel consumed per year during the construction phase (liters).[a,b]

Operating mode	South Portal Development Area		North Portal Operations Area[d]
	Diesel	Gasoline	Diesel
Higher-temperature	300,000[c]	20,000[c]	770,000
Lower-temperature	430,000 - 460,000[e,f]	20,000[e]	770,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel use from DIRS 150941-CRWMS M&O (2000, p. 6-3).
d. Source: Based on total fuel use from DIRS 152010-CRWMS M&O (2000, p. 48).
e. Source: Based on total fuel use from DIRS 155515-Williams (2001, Part 1, p. 9; and Part 2, p.7).
f. Source: Aging pad contribution derived from DIRS 152010-CRWMS M&O (2000, Table I-2).

Table G-17 lists pollutant releases from construction equipment for each operating mode. The emission rate for the annual concentration was calculated from the total fuel consumed, assuming the same amount of fuel would be consumed each year.

Table G-18 lists the impacts on air quality from construction equipment emission by operating mode as the maximum pollutant concentration in air and the percentage of the regulatory limit. Emissions from surface equipment during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards. The impacts from fuel use under Inventory Modules 1 and 2 would be the same as those under the Proposed Action because fuel use would be the same during construction.

G.1.4.6 Exhaust from Boiler

A proposed boiler in the North Portal Operations Area would emit the four criteria pollutants. The boiler would use diesel fuel and provide steam and hot water for the heating, ventilation, and air conditioning system. DOE assumed this boiler to be the same size as the boiler that would operate during the operation and monitoring phase (DIRS 152010-CRWMS M&O 2000, Table 6-2, p. 52). Table G-19 lists the annual emission rates of the boiler. To estimate the short-term (24 hours or less) emission rate, the analysis assumed the boiler would run 250 days (6,000 hours) per year. Given the annual boiler emissions, this was a conservative assumption because continuous operation 365 days (8,760 hours) per

Table G-17. Pollutant release rates from surface equipment during the construction phase.[a]

Pollutant	Period	Mass of pollutant per averaging period (kilograms)[b]		Emission rate[c] (grams per second)[d]	
		South	North	South	North
Higher-temperature operating mode					
Nitrogen dioxide	Annual	12,000	30,000	0.38	0.95
Sulfur dioxide	Annual	1,100	2,900	0.036	0.090
	24-hour	4.5	12	0.16	0.40
	3-hour	1.7	4.3	0.16	0.40
Carbon monoxide	8-hour	54	47	1.9	1.6
	1-hour	6.7	5.8	1.9	1.6
PM_{10}	Annual	1,100	2,700	0.034	0.085
	24-hour	4.2	11	0.15	0.37
Lower-temperature operating mode					
Nitrogen dioxide	Annual	17,000 - 18,000	30,000	0.55 - 0.58	0.95
Sulfur dioxide	Annual	1,600 - 1,700	2,900	0.051 - 0.055	0.091
	24-hour	6.5 - 6.9	12	0.22 - 0.24	0.40
	3-hour	2.4 - 2.6	4.3	0.22 - 0.24	0.40
Carbon monoxide	8-hour	62 - 63	47	2.1 - 2.2	1.6
	1-hour	7.7 - 7.9	5.8	2.1 - 2.2	1.6
PM_{10}	Annual	1,500 - 1,600	2,700	0.048 - 0.051	0.085
	24-hour	6.1 - 6.5	11	0.040 - 0.043	0.37

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-18. Air quality impacts from construction equipment during the construction phase (micrograms per cubic meter).[a]

Pollutant	Period	Maximum concentration	Regulatory limit[b]	Percent of regulatory limit
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.17	100	0.17
Sulfur dioxide	Annual	0.016	80	0.021
	24-hour	0.11	365	0.031
	3-hour	0.9	1,300	0.069
Carbon monoxide	8-hour	2.1	10,000	0.02
	1-hour	12	40,000	0.03
PM_{10}	Annual	0.015	50	0.03
	24-hour	0.1	150	0.07
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.18 - 0.19	100	0.18 - 0.19
Sulfur dioxide	Annual	0.017 - 0.018	80	0.022 - 0.023
	24-hour	0.12	365	0.033
	3-hour	0.95 - 0.98	1,300	0.073 - 0.075
Carbon monoxide	8-hour	2.1 - 2.2	10,000	0.021
	1-hour	12 - 13	40,000	0.031 - 0.032
PM_{10}	Annual	0.016	50	0.032 - 0.033
	24-hour	0.11	150	0.074 - 0.076

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Table G-19. Annual pollutant release rates (kilograms per year)[a] for the North Portal Operations Area boiler.[b,c]

Pollutant	Annual emission rate
Nitrogen dioxide	81,000
Sulfur dioxide	28,000
Carbon monoxide	20,000
PM_{10}	7,800

a. To convert kilograms to tons, multiply by 0.0011023.
b. Source: DIRS 152010-CRWMS M&O (2000, p. 52).
c. Numbers are rounded to two significant figures.

year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. In addition, specific information on the boiler stack height and exhaust air temperature (which would affect plume rise) has not been developed. These releases were assumed to be from ground level, which also tends to overestimate actual concentrations. Table G-20 lists releases of criteria pollutants by the boiler. Table G-21 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-20. Pollutant release rates from the boiler during the construction phase.[a,b]

Pollutant	Period	Mass of pollutant (kilograms)[c] per averaging time	Emission rate[d] (grams per second)[e]
Nitrogen dioxide	Annual	81,000	2.6
Sulfur dioxide	Annual	28,000	0.87
	24-hour	110	1.3
	3-hour	14	1.3
Carbon monoxide	8-hour	27	0.94
	1-hour	3.4	0.94
PM_{10}	Annual	7,800	0.25
	24-hour	32	0.36

a. Numbers are rounded to two significant figures.
b. These release rates also apply for the operation and monitoring phase (see Section G.1.5.6).
c. To convert kilograms to pounds, multiply by 2.2046.
d. Based on an 8-hour release for averaging periods of 24 hours or less.
e. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-21. Air quality impacts from boiler pollutant releases from the North Portal Operations Area during the construction phase (micrograms per cubic meter of pollutant).[a]

Pollutant	Period	Maximum concentration[b]	Regulatory limit[c]	Percent of regulatory limit[b]
Nitrogen dioxide	Annual	0.25	100	0.25
Sulfur dioxide	Annual	0.086	80	0.11
	24-hour	1.2	365	0.33
	3-hour	7.7	1,300	0.59
Carbon monoxide	8-hour	2.3	10,000	0.023
	1-hour	17	40,000	0.043
PM_{10}	Annual	0.025	50	0.050
	24-hour	0.34	150	0.23

a. These release rates also apply for the operation and monitoring phase (see Section G.1.5.6).
b. Numbers are rounded to two significant figures.
c. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from the boiler during the construction phase would produce small offsite (outside the land withdrawal area) criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

There would be no differences among repository operating modes. The air quality impacts from the boiler during the construction phase under Inventory Models 1 and 2 would be the same as those for the Proposed Action.

G.1.5 OPERATION AND MONITORING PHASE

This section describes the method DOE used to estimate air quality impacts during the operation and monitoring phase. As for the construction phase, impacts were evaluated for each year or for shorter time periods. Activities during this phase would include the continued development of the subsurface facilities, which would last 22 years for all operating modes. Emplacement activities in the surface and subsurface facilities would last 24 years, the first 22 years concurrent with continued development activities. Monitoring and maintenance would begin after the end of emplacement operations. For purposes of analysis, workers would use the following schedule for activities during the operation and monitoring phase: three 8-hour shifts a day, 5 days a week, 50 weeks a year. The maintenance of the excavated rock pile would occur in one 8-hour shift a day, 5 days a week, 50 weeks a year.

For Modules 1 and 2, the continued development of the subsurface facilities would last 36 years. Emplacement activities in the surface and subsurface facilities would continue concurrently with development operations but last an additional 2 years (38 years total).

The analysis estimated air quality impacts by calculating pollutant concentrations from various operation and monitoring activities. Emission rates were developed for each activity that would result in pollutant releases. The emission rates were multiplied by the unit release concentrations (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The principal emission sources of particulates would be dust emissions from concrete batch facility operations and fugitive dust emissions from excavation and storage on the excavated rock pile. In addition, fugitive dust from earthmoving activities would be emitted during final aging pad construction. Fuel combustion from maintenance of the excavated rock pile and emissions from the North Portal boiler would be principal sources of nitrogen dioxide, sulfur dioxide, and carbon monoxide. The following sections describe these sources in more detail.

G.1.5.1 Fugitive Dust from Surface Construction

For the lower-temperature repository operating mode with aging, fugitive dust would be emitted when the remaining aging pads were constructed during the operation and monitoring phase. If the pads were constructed at a rate of 0.12 square kilometer (30 acres) per year, as in the construction phase (see Section G.1.4.1), the estimated maximum PM_{10} air concentrations would be 0.05 percent and 0.12 percent of the annual and daily regulatory limits, respectively, for PM_{10}.

G.1.5.2 Fugitive Dust from Concrete Batch Facility

The concrete batch facility for the fabrication and curing of tunnel inverts and liners, remaining surface facility construction (solar power and spent nuclear fuel aging facilities), and dry cask construction would emit dust. Batch plant daily run times would be shorter than those during the construction phase, ranging from 0.5 to 2.0 hours. The dust release rate and potential air quality impacts are listed in Tables G-22 and G-23, respectively.

Table G-22. Dust release rates for the concrete batch facility during the operation and monitoring phase (PM_{10})[a]

Operating Mode	Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	5,200	0.12
	24-hour	21	1.9[d]
Lower-temperature	Annual	10,000 - 21,000	0.33 - 0.65
	24-hour	41 - 83	3.8 - 7.6[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Higher-temperature based on 0.5-hour, lower-temperature on 1-to-2 hour release period.

Table G-23. Particulate matter (PM_{10}) air quality impacts (micrograms per cubic meter) from the concrete batch facility during the operation and monitoring phase.

Operating Mode	Period	Maximum concentration[a]	Regulatory limit	Percent of regulatory limit[a]
Higher-temperature	Annual	0.02	50	0.040
	24-hour	0.32	150	0.21
Lower-temperature	Annual	0.040 - 0.079	50	0.079 - 0.16
	24-hour	0.63 - 1.3	150	0.42 - 0.84

a. Numbers are rounded to two significant figures.

G.1.5.3 Fugitive Dust from Subsurface Excavation

The excavation of rock from the repository would generate fugitive dust in the drifts. Some of the dust would reach the external atmosphere through the repository ventilation system. Fugitive dust emission rates from excavation during operations would be the same as those during the construction phase. Thus, the fugitive dust release rate and potential air quality impacts for excavation of rock would be the same as those listed in Tables G-7 and G-8. Air quality impacts from cristobalite released during excavation of the repository would be the same as those listed in Table G-8.

G.1.5.4 Fugitive Dust from Excavated Rock Pile

The disposal and storage of excavated rock on the excavated rock pile would release fugitive dust. The analysis used the same method to estimate fugitive dust releases from the excavated rock pile during operations that it used for the construction phase (See Section G.1.4.3). Table G-24 lists the areas of the active portion of the excavated rock pile for each operating mode. The total land area used for storage and the active portion of the excavated rock pile was based on the amount of rock that would be stored during operations (DIRS 150941-CRWMS M&O 2000, p. 6-11; DIRS 155515-Williams 2001, Part 1, p. 17; and Part 2, p. 15). Sections G.1.4.1 and G.1.4.3 compare the excavated rock pile areas.

Table G-24. Characteristics of excavated rock pile area during subsurface excavation activities of the operation and monitoring phase.[a]

Operating mode	Rock pile area (square kilometers)[b]	Pile height (meters)	Annual average active area (square kilometers)
Higher-temperature	0.87	6	0.055
Lower-temperature	0.86 - 1.4	8	0.053 - 0.10

a. Numbers are rounded to two significant figures.
b. To convert square kilometers to acres, multiply by 247.1.

While the land area used for storage of excavated rock during the operation and monitoring phase would be nearly twice as large as that used during the construction phase for the higher-temperature repository operating mode, the active area per year would be about half of that for construction due to the larger number of years over which continued development would occur (22 years compared to 5 years). The land area used during the operation and monitoring phase would be 3 to 5 times that used during the construction phase. The stored volume of excavated rock would be larger during the operation and monitoring phase than during the construction phase. Table G-25 lists fugitive dust releases from the excavated rock pile; Table G-26 lists potential air quality impacts as the pollutant concentration and percent of the regulatory limit.

Table G-25. Fugitive dust release rate from the excavated rock pile during the operation and monitoring phase (PM_{10}).[a]

Operating mode	Period	Emissions (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature	Annual	7,800	0.25
	24-hour	21	0.25
Lower-temperature	Annual	7,600 - 15,000	0.24 - 0.46
	24-hour	21 - 40	0.24 - 0.46

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-26. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the operation and monitoring phase (micrograms per cubic meter).

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.03	50	0.06
	24-hour	0.25	150	0.17
Lower-temperature	Annual	0.029 - 0.056	50	0.058 - 0.11
	24-hour	0.25 - 0.47	150	0.16 - 0.32
Cristobalite				
Higher-temperature	Annual	0.0084	10[c]	0.084
Lower-temperature	Annual	0.0081 - 0.016	10[c]	0.081 - 0.16

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during the operation and monitoring phase would produce very small offsite (outside the land withdrawal area) PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-26 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The site boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

The Module 1 and 2 analysis used the same technique as for the Proposed Action. The stored rock pile area for Inventory Modules 1 and 2 would be approximately twice the size of the piles for the Proposed

Action operating modes, but the excavation period would be extended as well. The estimated air quality impacts would be only 1.2 times larger for Modules 1 and 2.

G.1.5.5 Exhaust from Surface Equipment

Surface equipment would emit the four criteria pollutants during excavated rock pile maintenance, surface operation, and any remaining surface facility construction. The analysis used the same method to determine air quality impacts for surface equipment during operations used for the construction phase (see Section G.1.4.5). Table G-15 lists the pollutant release rates of the equipment. Table G-27 lists the average amount of fuel consumed each year during the operation and monitoring phase at the South Portal Development Area.

Table G-27. Annual amount of fuel (liters)[a] consumed during the operation and monitoring phase.[b]

Operating mode	Diesel	Gasoline
Higher-temperature[c]	170,000	4,500
Lower-temperature[d]	210,000 - 400,000[e]	4,500

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel use from DIRS 150941-CRWMS M&O (2000, pp. 6-8 and 6-13).
d. Source: DIRS 155515-Williams (2001, Part 1, pp. 14 and 18; Part 2, pp. 12 and 16).
e. Source: Derived using DIRS 152010-CRWMS M&O (2000, Table I-2).

Table G-28 lists pollutant release rates for surface equipment during operations activities of the operation and monitoring phase. Monitoring activity emissions would be much smaller. Table G-29 lists potential air quality impacts.

Table G-28. Pollutant release rates from surface equipment during the operation and monitoring phase.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature operating mode			
Nitrogen dioxide	Annual	13,000	0.41
Sulfur dioxide	Annual	1,200	0.039
	24-hour	4.9	0.17
	3-hour	1.8	0.17
Carbon monoxide	8-hour	28	0.97
	1-hour	3.5	0.97
PM_{10}	Annual	1,100	0.036
	24-hour	4.6	0.16
Lower-temperature operating mode			
Nitrogen dioxide	Annual	14,000 - 20,000	0.46 - 0.62
Sulfur dioxide	Annual	1,400 - 1,900	0.044 - 0.059
	24-hour	5.5 - 7.5	0.19 - 0.26
	3-hour	2.1 - 2.8	0.19 - 0.26
Carbon monoxide	8-hour	30 - 38	1 - 1.3
	1-hour	3.8 - 4.8	1 - 1.3
PM_{10}	Annual	1,300 - 1,700	0.041 - 0.055
	24-hour	5.1 - 7	0.18 - 0.24

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-29. Air quality impacts from surface equipment during the operation and monitoring phase (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.052	100	0.052
Sulfur dioxide	Annual	0.0049	80	0.0062
	24-hour	0.034	365	0.0093
	3-hour	0.27	1,300	0.021
Carbon monoxide	8-hour	0.57	10,000	0.0056
	1-hour	3.3	40,000	0.0083
PM_{10}	Annual	0.0046	50	0.0091
	24-hour	0.032	150	0.021
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.058 - 0.078	100	0.058 - 0.078
Sulfur dioxide	Annual	0.0055 - 0.0073	80	0.0070 - 0.0094
	24-hour	0.038 - 0.051	365	0.01 - 0.014
	3-hour	0.3 - 0.41	1,300	0.023 - 0.031
Carbon monoxide	8-hour	0.62 - 0.78	10,000	0.006 - 0.0076
	1-hour	3.6 - 4.5	40,000	0.009 - 0.011
PM_{10}	Annual	0.0051 - 0.0069	50	0.01 - 0.014
	24-hour	0.035 - 0.047	150	0.024 - 0.032

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Emissions from surface equipment during operation and monitoring would produce very small concentrations of offsite (outside the land withdrawal area) criteria pollutants. All estimated concentrations would be less than 1 percent of the regulatory standards.

Modules 1 and 2 would use fuel at a slightly higher rate than that for the Proposed Action at the South Portal Development Area, but at a slightly lower rate at the North Portal Operations Area. The resulting impact under Modules 1 and 2 would be the same; all estimated concentrations would be less than 1 percent of the regulatory standard.

G.1.5.6 Exhaust from Boiler

A boiler in the North Portal Operations Area would emit the four criteria pollutants. The annual emission rates are listed in Table G-19. There would be small variations in the boiler emissions for the transportation and waste packaging options because of different operational requirements. The emissions listed in Table G-19 are for the combination of legal-weight truck transport and uncanistered waste scenario, which would require the largest boiler because a larger Waste Handling Building would be required (DIRS 152010-CRWMS M&O 2000, p. 52). (The analysis assumed that identical boilers would operate under all operating modes and that the boiler would run 250 days (6,000 hours) per year.) Given an annual emission rate, this was a conservative assumption because continuous operation 365 days (8,760 hours) per year would result in lower daily emissions. This assumption considered periods when the boiler would not be operating. The actual period of boiler operation is not known. Pollutant release rates during the operation and monitoring phase would be the same as those listed in Table G-20. Table G-21 lists estimated potential air quality impacts as pollutant concentrations in air and percent of regulatory limit. Emissions from the boiler during the operation and monitoring phase would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

The estimated air quality impacts from boilers for Inventory Modules 1 and 2 during the operation and monitoring phase would be the same as those for the Proposed Action.

G.1.6 CLOSURE PHASE

This section describes the method used to estimate air quality impacts during the closure phase at the proposed repository. The closure phase is defined by the length of the subsurface closure activities, which would be directed from the South Portal Development Area. Subsurface closure for the higher-temperature operating mode of the Proposed Action would last 10 years, while subsurface closure for the lower-temperature operating mode would range from 11 to 17 years. Surface facility closure at the North Portal Operations Area would last 6 years for all operating modes. Closure of any aging pads that might be present under the lower-temperature operating mode was assumed to take place after surface facility closure was completed. Closure for Inventory Modules 1 and 2 would have a longer subsurface closure period, lasting 12 years for the higher-temperature operating mode and from 16 to 23 years for the lower-temperature operating mode. Surface facility closure for Inventory Modules 1 and 2 would be the same as for the Proposed Action. The work schedule would be one 8-hour shift per day, 5 days a week, 50 weeks a year.

Air quality impacts were estimated by calculating pollutant concentrations from various closure activities. Emission rates were developed for each activity that would result in releases of pollutants. These pollutant emission rates were then multiplied by the unit release concentration (see Section G.1.3) to calculate the pollutant concentration for comparison to the various regulatory limits.

The sources of particulates would be emissions from the backfill plant and the concrete batch facility and fugitive dust from closure activities on the surface and the reclamation of material from the excavated rock pile for backfill. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide during closure would be fuel combustion. The following sections describe these sources in more detail.

G.1.6.1 Dust from Backfill Plant

The Closure Backfill Preparation Plant would process (separate, crush, screen, and wash) rock from the excavated rock pile for use as backfill for the underground access openings (DIRS 104523-CRWMS M&O 1999, pp. 4-77 and 4-78). The facility would have the capacity to handle 91 metric tons (100 tons) an hour (DIRS 104523-CRWMS M&O 1999, pp. 4-77 and 4-78). For purposes of analysis, the backfill plant would run 6 hours a shift, 2 shifts a day, 5 days a week, 50 weeks a year during the closure phase.

The plant was assumed to have emissions similar to a crushed-stone processing plant. Table G-30 lists the emission rates for various activities associated with a crushed stone processing plant (DIRS 101824-EPA 1995, pp. 11.19.2-1 to 11.19.2-8). Table G-31 lists estimated pollutant release rates for the backfill plant. Table G-32 lists potential air quality impacts as pollutant concentrations in air and percent of regulatory limit.

Table G-30. Emission rates from a crushed stone processing plant.[a,b]

Source/activity	Emission rate (kilogram[c] per 1,000 kilograms of material processed)
Dump to conveyor or truck	0.00005
Screening	0.0076
Crusher	0.0012
Fine screening	0.036

a. Source: DIRS 101824-EPA (1995, pp. 11.19.2-1 to 11.19.2-8).
b. Numbers are rounded to two significant figures.
c. To convert kilograms to pounds, multiply by 2.2046.

Table G-31. Dust release rates from the backfill plant (PM_{10}).[a]

Period	Emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	12,000 per year	0.39
24-hour	49 per day	1.1[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 12-hour release period.

Table G-32. Particulate matter (PM_{10}) air quality impacts from backfill plant (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.047	50	0.093
24-hour	1.1	150	0.71

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Dust emissions from the backfill plant would produce small PM_{10} concentrations. Both annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

For Modules 1 and 2, the estimated air quality impacts for the backfill plant would be the same as those for the Proposed Action.

G.1.6.2 Fugitive Dust from Concrete Batch Facility

A concrete batch facility for the fabrication of seals would be similar to the facility that would operate during the construction and operation and monitoring phases (see Sections G.1.4.4 and G.1.5.2). The only difference would be that it would run only ten 3-hour shifts a year per concrete seal (DIRS 104523-CRWMS M&O 1999, p. 4-78). The analysis assumed that two seals per year would be produced. Table G-12 lists activities associated with the concrete batch facility and their emissions. Table G-33 lists emissions from the concrete batch facility during closure. Table G-34 lists potential air quality impacts as pollutant concentration in air and percent of regulatory limit.

Table G-33. Dust release rates from the concrete batch facility during the closure phase (PM_{10}).[a]

Period	Mass of pollutant (kilograms)[b]	Emission rate (grams per second)[c]
Annual	1,300	0.043
24-hour	120	11[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on a 3-hour release period.

Dust emissions from the concrete batch facility during closure would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be less than 1 percent and around 1.3 percent, respectively, of the regulatory standards.

For Modules 1 and 2, the estimated air quality impacts from the concrete batch facility during the closure phase would be the same as those for the Proposed Action.

Table G-34. Particulate matter (PM_{10}) air quality impacts from the concrete batch facility during the closure phase (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.0051	50	0.01
24-hour	1.9	150	1.3

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.6.3 Fugitive Dust from Closure Activities

Closure activities such as smoothing and reshaping the excavated rock pile and demolishing buildings would produce virtually the same fugitive dust releases as construction activities because they would disturb nearly the same amount of land. Sources of dust from surface demolition and decommissioning activities would include the North Portal area and roads, South portal area and roads, ventilation shaft areas and access roads, the excavated rock pile, solar power generating facility, concrete batch plant and, for some aspects of the lower-temperature operating mode, concrete spent nuclear fuel aging pads. Because some of these surface facilities would be needed to support subsurface closure activities, releases from surface demolition and decommissioning would last for the duration of the closure phase, not just the 6 years of closure at the North Portal Operations Area. Potential dust releases and impacts from the lower-temperature operating mode would be somewhat lower than from the higher-temperature operating mode because a similar scope of activities would occur over the longer closure phase. Dust release rates and potential air quality impacts are listed in Tables G-35 and G-36, respectively.

Table G-35. Fugitive dust releases from surface demolition and decommissioning (PM_{10}).[a]

Operating mode	Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Higher-temperature	Annual	62,000 per year	2
	24-hour	250 per day	8.6[d]
Lower-temperature	Annual	52,000 - 60,000 per year	1.6 - 1.9
	24-hour	210 - 240 per day	7.3 - 8.3[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Table G-36. Estimated fugitive dust air quality impacts (micrograms per cubic meter) from surface demolition and decommissioning (PM_{10}).[a]

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of limit[a]
Higher-temperature	Annual	0.24	50	0.47
	24-hour	1.6	150	1.1
Lower-temperature	Annual	0.2 - 0.23	50	0.4 - 0.46
	24-hour	1.4 - 1.6	150	0.92 - 1.1

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

Fugitive dust emissions would produce small offsite PM_{10} concentrations. The annual and 24-hour average concentrations of PM_{10} would be less than 0.5 percent and around 1.1 percent, respectively, of the regulatory standards. The estimated air quality impacts from surface facility closure for Inventory Modules 1 and 2 would be the same as those for the Proposed Action.

G.1.6.4 Fugitive Dust from Excavated Rock Pile

During backfill operations, fugitive dust would occur from the removal of excavated rock from the storage pile. The analysis used the same method to estimate fugitive dust emission from the excavated rock pile during the closure phase that it used for the construction phase (Section G.1.4.3). Table G-37 lists the total area of the excavated rock pile disturbed and the active portion, based on the amount of material to be removed from the pile (DIRS 104523-CRWMS M&O 1999, p. 6-39; DIRS 150941-CRWMS M&O 2000, p. 6-24). The analysis assumed that the rock used in backfill would be from a limited area of the excavated rock pile, rather than from all over the pile. Table G-38 lists fugitive dust releases from the excavated rock pile. Table G-39 lists potential air quality impacts from the pile as pollutant air concentration and percent of regulatory limit.

Table G-37. Characteristics of excavated rock pile during the closure phase.[a]

Operating mode	Rock pile area (square kilometers)[b]	Pile height (meters)[c]	Annual average active area (square kilometers)
Higher-temperature	0.39	6	0.077
Lower-temperature	0.54 - 0.83	8	0.059 - 0.065

a. Numbers are rounded to two significant figures.
b. To convert square kilometers to acres, multiply by 247.1.
c. To convert meters to feet, multiply by 3.2808.

Table G-38. Fugitive dust release rates from the excavated rock pile during the closure phase (PM_{10}).[a]

Operating mode	Period	Emission (kilograms)[b]	Emission rate[c] (grams per second)[d]
Higher-temperature	Annual	11,000	0.35
	24-hour	30	0.35
Lower-temperature	Annual	8,300 - 9,200	0.26 - 0.29
	24-hour	23 - 25	0.26 - 0.29

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on a continuous release.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-39. Fugitive dust (PM_{10}) and cristobalite air quality impacts from the excavated rock pile during the closure phase (micrograms per cubic meter).

Operating mode	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
PM_{10}				
Higher-temperature	Annual	0.042	50	0.084
	24-hour	0.36	150	0.24
Lower-temperature	Annual	0.032 - 0.035	50	0.064 - 0.070
	24-hour	0.27 - 0.30	150	0.18 - 0.20
Cristobalite				
Higher-temperature	Annual	0.012	10[c]	0.12
Lower-temperature	Annual	0.0089 - 0.0098	10[c]	0.089 - 0.098

a. Numbers are rounded to two significant figures.
b. Source: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.
c. This value is a benchmark; there is no regulatory limit for cristobalite. See Section G.1.

Fugitive dust emissions from the excavated rock pile during closure would produce small offsite PM_{10} concentrations. Both the annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-39 also lists potential air quality impacts for releases of cristobalite. The methods used were the same as those described in Section G.1.4.2 for the construction phase, where cristobalite was assumed to be 28 percent of the fugitive dust released, based on its percentage in parent rock. The land withdrawal area boundary cristobalite concentration would be small, about 0.1 percent of the benchmark level discussed in Section G.1.

For Modules 1 and 2, the same technique was used. The estimated active area of the rock pile would be 13 percent larger for the higher-temperature repository operating mode and 12 to 30 percent larger for the lower-temperature repository operating mode. The estimated air quality impacts would be just slightly larger than those of the Proposed Action because of longer closure times under Modules 1 and 2. Impacts would be less than 1 percent of the regulatory standards.

G.1.6.5 Exhaust Emissions from Surface Equipment

The consumption of diesel fuel by surface equipment and backfilling equipment would emit the four criteria pollutants during closure. The analysis used the same method to determine pollutant release rates during closure as was used for the construction phase (see Section G.1.4.5). Table G-15 lists the estimated pollutant release rates of the equipment that would consume the fuel. Table G-40 lists the average amount of fuel consumed per year. The length of the closure phase is discussed in Section G.1.6. The analysis assumed backfilling operations would last 2 years (DIRS 150941-CRWMS M&O 2000, p. I-2).

Table G-40. Annual amount of fuel consumed (liters)[a] during the closure phase.[b]

Operating mode	South Portal diesel	North Portal diesel[d]	Backfilling diesel[e,f]	Maximum annual usage
Higher-temperature	150,000[c]	620,000	1,250,000	2,000,000
Lower-temperature	150,000-170,000[g]	620,000	1,250,000	2,000,000

a. To convert liters to gallons, multiply by 0.26418.
b. Numbers are rounded to two significant figures.
c. Source: Based on total fuel consumed from DIRS 150941-CRWMS M&O (2000, p. 6-23).
d. Source: Based on total fuel consumed from DIRS 152010-CRWMS M&O (2000, p. 57).
e. Source: Based on total fuel consumed from DIRS 150941-CRWMS M&O (2000, p. I-2).
f. Backfilling operations would last only 2 years.
g. Source: Based on total fuel consumed from DIRS 155515-Williams (2001, Part 1, p. 25; and Part 2, p. 22).

Tables G-41 and G-42 list pollutant releases from surface diesel consumption. Table G-43 lists potential air quality impacts as pollutant concentrations in air and percent of regulatory limit. Concentrations would be less than 1 percent of the regulatory limit for the range of operating modes.

G.1.7 RETRIEVAL SCENARIO

This section describes the method used to estimate air quality impacts during possible retrieval at the proposed repository. Retrieval is not part of the Proposed Action; DOE evaluated it only as a contingent action of the higher-temperature operating mode. The retrieval contingency would last 14 years and include additional construction activities and retrieval operations. Construction of the retrieval storage facility and pads would take 10 years (DIRS 152010-CRWMS M&O 2000, p. I-17). There would be an initial 3-year period of construction (DIRS 152010-CRMWS M&O 2000, p. I-16), followed by 7 years of construction that would take place concurrently with retrieval operations. Retrieval operations would last

Table G-41. Pollutant release rates from surface equipment during the closure phase.[a]

Pollutant	Period	Mass of pollutant per averaging period (kilograms)[b]		Emission rate[c] (grams per second)[d]	
		South	North	South	North
Higher-temperature operating mode					
Nitrogen dioxide	Annual	5,900	24,000	0.19	0.76
Sulfur dioxide	Annual	560	2,300	0.018	0.073
	24-hour	2.2	9.2	0.078	0.32
	3-hour	0.84	3.4	0.078	0.32
Carbon monoxide	8-hour	9.1	37	0.31	1.3
	1-hour	1.1	4.6	0.31	1.3
PM_{10}	Annual	520	2,100	0.017	0.068
	24-hour	2.1	8.6	0.073	0.3
Lower-temperature operating mode					
Nitrogen dioxide	Annual	5,900 - 6,600	24,000	0.19 - 0.21	0.76
Sulfur dioxide	Annual	560 - 625	2,300	0.018 - 0.02	0.073
	24 - hour	2.2 - 2.5	9.2	0.078 - 0.087	0.32
	3 - hour	0.84 - 0.94	3.4	0.078 - 0.087	0.32
Carbon monoxide	8 - hour	9.1 - 10	37	0.31 - 0.35	1.3
	1 - hour	1.1 - 1.3	4.6	0.31 - 0.35	1.3
PM_{10}	Annual	520 - 580	2,100	0.017 - 0.018	0.068
	24 - hour	2.1 - 2.3	8.6	0.073 - 0.081	0.3

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-42. Pollutant release rates from diesel backfilling equipment during the closure phase for the higher- and lower-temperature repository operating modes.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	49,000	1.6
Sulfur dioxide	Annual	4,700	0.15
	24-hour	19	0.65
	3-hour	7.0	0.65
Carbon monoxide	8-hour	75	2.6
	1-hour	9.4	2.6
PM_{10}	Annual	4,400	0.14
	24-hour	17	0.60

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release for averaging periods of 24 hours or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

11 years (DIRS 152010-CRMWS M&O 2000, p. I-17), continuing 4 years after the construction was completed. If the lower-temperature operating mode with aging was implemented, the aging pads constructed could be used for storage of retrieved waste packages. The analysis considered concurrent air quality impacts of retrieval and construction. The retrieval scenario work schedule would be one 8-hour shift a day, 5 days a week, 50 weeks a year.

The analysis estimated air quality impacts by calculating pollutant concentrations from various activities associated with retrieval. Emission rates were developed for each activity that would result in releases of pollutants. These rates were multiplied by the unit release concentration (see Section G.1.3) to calculate pollutant concentrations for comparison to the various regulatory limits. The principal sources of particulates would be fugitive dust emissions from construction activities associated with the waste retrieval facility, and a concrete batch facility. The principal source of nitrogen dioxide, sulfur dioxide, and carbon monoxide would be fuel combustion during the construction of the waste retrieval facility and during retrieval of the waste. The following sections describe these sources in more detail.

Table G-43. Air quality impacts (micrograms per cubic meter) from surface equipment during the closure phase.

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Higher-temperature operating mode				
Nitrogen dioxide	Annual	0.3	100	0.3
Sulfur dioxide	Annual	0.029	80	0.037
	24-hour	0.2	365	0.055
	3-hour	1.6	1,300	0.12
Carbon monoxide	8-hour	2.4	10,000	0.024
	1-hour	14	40,000	0.035
PM_{10}	Annual	0.027	50	0.054
	24-hour	0.19	150	0.12
Lower-temperature operating mode				
Nitrogen dioxide	Annual	0.3 - 0.31	100	0.31
Sulfur dioxide	Annual	0.029	80	0.037
	24-hour	0.20	365	0.055
	3-hour	1.6	1,300	0.12
Carbon monoxide	8-hour	2.4	10,000	0.024
	1-hour	14	40,000	0.035
PM_{10}	Annual	0.027	50	0.054
	24-hour	0.19	150	0.12

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.7.1 Fugitive Dust from Construction of Retrieval Storage Facility

Construction activities such as earth moving and truck traffic would produce fugitive dust during the construction of the retrieval storage facility. The analysis used the same method to estimate fugitive dust releases during retrieval as that for construction (see Section G.1.4.1). The amount of land disturbed to build the retrieval storage facility and storage pads would be 1.5 square kilometer (380 acres) (DIRS 152010-CRWMS M&O 2000, Table I-2, p. I-22).

Table G-44 lists fugitive dust release rates from construction of the retrieval facility and storage pad. Table G-45 lists air quality impacts as pollutant concentration in air and percent of regulatory limit. Fugitive dust emissions from construction of the retrieval facility and storage pad would produce small offsite (outside the land withdrawal area) PM_{10} concentrations. Annual and 24-hour average concentrations of PM_{10} would be less than 1 percent of the regulatory standards for all operating modes.

Table G-44. Fugitive dust release rates from surface construction of retrieval storage facility and storage pad (PM_{10}).[a]

Period	Pollutant emission (kilograms)[b]	Emission rate (grams per second)[c]
Annual	34,000 per year	1.1
24-hour	140 per day	4.8[d]

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert grams per second to pounds per hour, multiply by 7.9366.
d. Based on an 8-hour release period.

Table G-45. Fugitive dust (PM_{10}) air quality impacts from surface construction of the retrieval storage facility and storage pad (micrograms per cubic meter).

Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Annual	0.11	50	0.22
24-hour	0.87	150	0.58

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.1.7.2 Concrete Batch Plant

The concrete batch plant used during the retrieval phase was assumed to operate 3 hours per day, 250 days per year. The emissions would be approximately 85 percent of those indicated for the higher-temperature repository operating mode concrete batch plant during the construction phase (see Tables G-13 and G-14). The numbers would be lower because of the lower daily operating time (3 hours per day rather than 3.5 hours per day). The annual and 24-hour averaged concentrations of PM_{10} from the concrete batch plant would be less than 1 percent and 2 percent of the regulatory standards, respectively.

G.1.7.3 Exhaust from Surface Equipment

Surface equipment would emit the four criteria pollutants during retrieval operations and during the construction of the retrieval storage facility and storage pad. The analysis used the same method to estimate pollutant release rates from fuel consumed by construction equipment during retrieval that was used for the construction phase (see Section G.1.4.5). During retrieval operations, fuel would be consumed at the South Portal Development Area; during the construction of the retrieval facility and storage pad, fuel would be consumed at the North Portal Operations Area. Table G-15 lists the pollutant release rates of the equipment that would consume the diesel fuel. The fuel would be used for surface construction and surface and subsurface retrieval operations. Total annual usage for the Proposed Action would be 250,000 liters (66,000 gallons) of diesel fuel at the South Portal; 190,000 liters (50,000 gallons) at the North Portal; and 18,000 liters (4,800 gallons) for retrieval operations at the North Portal.

Table G-46 lists pollutant release rates for surface equipment during retrieval. Table G-47 lists the potential air quality impacts. Emissions from surface equipment during retrieval would produce small offsite criteria pollutant concentrations. All concentrations would be less than 1 percent of the regulatory standards.

Table G-46. Pollutant release rates from surface equipment during the retrieval scenario.[a]

Pollutant	Period	Mass of pollutant per averaging time (kilograms)[b]	Emission rate[c] (grams per second)[d]
Nitrogen dioxide	Annual	9,100	0.29
Sulfur dioxide	Annual	860	0.027
	24-hour	3.4	0.12
	3-hour	1.3	0.12
Carbon monoxide	8-hour	14	0.48
	1-hour	1.7	0.48
PM_{10}	Annual	800	0.025
	24-hour	3.2	0.11

a. Numbers are rounded to two significant figures.
b. To convert kilograms to pounds, multiply by 2.2046.
c. Based on an 8-hour release period for averaging periods of 24 hour or less.
d. To convert grams per second to pounds per hour, multiply by 7.9366.

Table G-47. Air quality impacts from surface equipment during the retrieval scenario (micrograms per cubic meter of pollutant).

Pollutant	Period	Maximum concentration[a]	Regulatory limit[b]	Percent of regulatory limit[a]
Nitrogen dioxide	Annual	0.035	100	0.035
Sulfur dioxide	Annual	0.003	80	0.0042
	24-hour	0.023	365	0.0062
	3-hour	0.18	1,300	0.014
Carbon monoxide	8-hour	0.28	10,000	0.0027
	1-hour	1.6	40,000	0.004
PM_{10}	Annual	0.0031	50	0.0061
	24-hour	0.021	150	0.014

a. Numbers are rounded to two significant figures.
b. Sources: 40 CFR 50.4 through 50.11 and Nevada Administrative Code 445B.391.

G.2 Radiological Air Quality

This section describes the methods DOE used to analyze potential radiological impacts to air quality at the proposed Yucca Mountain Repository during the construction, operation and monitoring, and closure phases, and a possible retrieval scenario. The results are presented in Chapter 4, Section 4.1.2. It discusses the radioactive noble gas krypton-85, which would be released from surface facilities during the handling of spent nuclear fuel, and naturally occurring radon-222 and its radioactive decay products, which would be released from the rock to the subsurface facility and then to the ventilation air. The excavated rock pile would not be a notable additional source of radon-222, because the rock would not have enhanced concentrations of uranium or radium (the sources of radon-222) in comparison to surface rock. Somewhat higher concentrations of radon-222 could be present at the rock pile itself but, in general, concentrations of radon-222 released from the excavated rock pile would not differ greatly from naturally occurring surface concentrations of radon.

G.2.1 LOCATIONS OF HYPOTHETICALLY EXPOSED INDIVIDUALS AND LOCATIONS

Members of the public and noninvolved workers could be exposed to atmospheric releases of radionuclides from repository activities. Doses to the maximally exposed individual and population within 80 kilometers (50 miles) were evaluated for the public. The dose to the maximally exposed noninvolved worker and the noninvolved worker populations at the repository and at the Nevada Test Site were also evaluated.

Public

The location of the maximally exposed individual member of the public would be at the southern boundary of the land withdrawal area. This was determined to be the location of unrestricted public access that would have the highest annual average concentration of airborne radionuclides (see Section G.2.2). Twenty kilometers (12 miles) was used as a representative distance to the exposed individual location for releases to air from the North Portal, South Portal, and one to nine exhaust ventilation shafts over three project phases and the range of operating modes. The locations calculated for nonradiological air quality impacts (Section G.1.2) are somewhat different because the analysis estimated exposure to nonradiological pollutants for acute (short-term) exposures (1 to 24 hours) and for annual (continuous) exposures.

Table G-48 lists the estimated population of about 76,000 within 80 kilometers (50 miles) of the repository. This is the predicted population for 2035, based on projected changes in the region, including the towns of Beatty, Pahrump, Indian Springs, and the surrounding rural areas. These projections are based on information from State and local sources (see Chapter 3, Section 3.1.7) The population in the vicinity of Pahrump was included in Table G-48 and evaluated for air quality impacts, even though the population extends beyond the 80-kilometer region. The analysis calculated both annual population dose and cumulative dose for the project phases of 115 to 341 years of construction, operation and monitoring, and closure.

Table G-48. Projected 2035 population distribution within 80 kilometers (50 miles) of repository site.[a,b,c]

	Distance (kilometers)										
Direction	8	16	24	32	40	48	56	64	72	80	***Totals***
S	0	0	49	660	1,376	363	0	19	0	0	***2,467***
SSW	0	0	0	928	179	0	0	4	0	0	***1,111***
SW	0	0	0	0	0	0	596	62	0	0	***658***
WSW	0	0	0	0	0	0	0	0	107	0	***107***
W	0	0	0	1,092	10	0	0	0	0	0	***1,102***
WNW	0	0	63	1,829	0	0	0	0	0	11	***1,903***
NW	0	0	0	50	2	0	0	5	50	0	***105***
NNW	0	0	0	0	0	0	0	0	0	0	***0***
N	0	0	0	0	0	0	0	0	0	0	***0***
NNE	0	0	0	0	0	0	0	0	0	0	***0***
NE	0	0	0	0	0	0	0	0	0	0	***0***
ENE	0	0	0	0	0	0	0	0	0	0	***0***
E	0	0	0	0	0	0	0	0	0	0	***0***
ESE	0	0	0	0	0	0	0	0	2,686	0	***2,686***
SE	0	0	0	0	0	0	50	0	0	1,086	***1,136***
SSE	0	0	0	0	41	187	49	177	18,249	46,080[d]	***64,783***
Grand Total											***76,058***

a. Source: DIRS 155105-Baxter (2001, all).
b. To convert kilometers to miles, multiply by 0.62137.
c. There is a 4-kilometer (about 2.5-mile)-radius area around the North Portal, from which the analysis determined the 80-kilometer (50-mile) area.
d. Includes the Pahrump vicinity population, which extends beyond the 80-kilometer region.

Noninvolved (Surface) Workers

The analysis assumed noninvolved workers on the surface would be at the site 2,000 hours a year (8 hours a day, 5 days a week, 50 weeks a year), or about 23 percent of the total number of hours in a year (8,760). All surface workers, regardless of work responsibility, were considered to be noninvolved workers for evaluation of exposure to radon-222 and radon decay products released from the subsurface facilities. For releases of noble gases (principally krypton-85) from spent fuel handling activities, potentially exposed noninvolved workers would be all surface workers except those in the Waste Handling and Waste Treatment Buildings. The noble gases would be released from the Stack of the Waste Handling Building and workers in these facilities would not be exposed.

The maximally exposed noninvolved worker location for releases of radon and its decay products would be in the South Portal Development Area for all project phases. During the construction phase and development activities ventilation air from repository excavation activities would be exhausted through the South Portal, resulting in the highest potential exposure to radon and radon decay products. The analysis assumed that during these periods this worker would be in the office building about 100 meters (330 feet) northeast of the South Portal. This location is not directly in front of the South Portal but offset from what would be the ventilation plume centerline, so the atmospheric dispersion factor is reduced somewhat (see Section G.2.2). There would be no South Portal ventilation during monitoring activities and the closure phase, but the maximally exposed noninvolved worker would still be in the South Portal Development Area. For releases from the Waste Handling Building during spent fuel handling operations, the maximally exposed noninvolved worker location would be in the North Portal

Operations Area. When both surface and subsurface sources of radionuclides during operations are considered, the maximally exposed worker location would be the South Portal Development Area.

The population and distribution of repository workers required to staff the repository would depend on the specific parameters of the operating mode. The highest labor requirements listed in Table G-49 would be for the lower-temperature operating mode with spent fuel aging. The lowest labor requirements would be for the higher-temperature operating mode.

Table G-49. Noninvolved (surface) worker population distribution for Yucca Mountain air quality analyses.[a,b,c,d]

		Fulltime equivalent worker years	
		Operating mode	
Worker location	Time period	Higher-temperature	Lower-temperature
Construction phase	5 years		
North Portal		4,000	3,800 - 4,100
South Portal		490	490
Operation and monitoring			
Emplacement and development			
North Portal (exposure to subsurface releases)	24 or 50 years[e]	31,000	31,000 - 50,000
South Portal	24 years	1,500	1,600 - 2,100
North Portal (exposure to WHB/WTB releases)	24 years	8,200[d]	8,200 - 9,100[f]
Monitoring and maintenance			
North Portal – decontamination	3 years	3,400	2,800 - 3,400
North Portal – monitoring and maintenance	73 - 297 years	2,800	3,700 - 11,000
South Portal	76 - 300 years	930	1,200 - 3,700
Closure			
North Portal	6 years	4,000	4,000
South Portal	10 - 17 years	420	470 - 720
Retrieval[g]			
North Portal – construction	10 years	1,800	(h)
North Portal – operations	11 years	1,200	(h)
South Portal – operations	11 years	150	(h)

a. Sources: Appendix F, Table F-3 and DIRS 150941-CRWMS M&O (2000, p. 4-52).
b. Numbers are rounded to two significant figures.
c. Fifteen percent of fulltime equivalent subsurface worker time would be spent on the surface in the South Portal Development Area (based on DIRS 150941-CRWMS M&O (2000, p. 4-52).
d. Fulltime equivalent worker years for the time period listed.
e. 50 years for aging only.
f. Total workers exposed to krypton-85 releases from surface facilities. All noninvolved workers, does not include involved workers in Waste Handling or Waste Treatment Buildings; includes 15 percent of subsurface workers.
g. The retrieval period would last 14 years. There would be 3 years of initial construction followed by 7 additional years of construction during operations. Retrieval operations would last 11 years. Sources: DIRS 152010-CRWMS M&O (2000, pp. I-16 to I-20); DIRS 150941-CRWMS M&O (2000, pp. 6-19 to 6-20).
h. The retrieval contingency is not a part of the Proposed Action. Results are in Chapter 4, Section 4.2.1.2.2.

The estimated population of workers in the South Portal Development Area was based on the number of full-time equivalents of subsurface workers. This would include full-time South Portal Development Area workers as well as workers who would be on the surface for only a portion of a day as they prepared for underground work. The number of subsurface workers located in the South Portal Development Area was estimated to be 15 percent of the total subsurface workers. Also evaluated as a potentially exposed noninvolved worker population were DOE workers at the Nevada Test Site. The analysis used a Nevada Test Site worker population of 6,576 workers (DIRS 101811-DOE 1996, Volume I, Appendix A, p. A-69).

For purposes of analysis, all these workers were assumed to be about 50 kilometers (30 miles) east-southeast of the repository at Mercury, Nevada.

G.2.2 METEOROLOGICAL DATA AND ATMOSPHERIC DISPERSION FACTORS

The basis for the atmospheric dispersion factors used in the dose calculations was a joint frequency distribution file for 1993 to 1997. These data were based on site-specific meteorological measurements made at air quality and meteorology monitoring Site 1, combined for 1993 to 1997 (DIRS 102877-CRWMS M&O 1999, p. 11). Site 1 is about 1 kilometer (0.6 mile) south of the proposed North Portal surface facility location. Similar topographic exposure would lead to similar prevailing northerly and southerly winds at both locations. DOE used these data because an analysis of the data collected at all the sites showed Site 1 to be most representative of the surface facilities (DIRS 102877-CRWMS M&O 1999, p. 7). The joint frequency data are somewhat different from the more detailed meteorological data used for the nonradiological air quality analysis. The dose calculations required only annual average data because they compare doses to annual limits, whereas criteria pollutant limits have 1-, 3-, 8-, or 24-hour averaging periods and the calculation of short-term criteria pollutant concentrations required hourly meteorological data. The nonradiological analysis also calculated concentrations only at the land withdrawal area boundary, not at onsite locations where workers would be.

Depending on the operating mode, project phase, and level of activity, subsurface ventilation air could be exhausted from three to nine exhaust shafts and the South Portal. These exhaust shafts would be on the ridge above the repository. Table G-50 lists the distribution of exhaust ventilation air among the subsurface release points for the operating modes and project phases and activities. These distributions were used to calculate annual average atmospheric dispersion factors for radon releases from the subsurface.

The GENII software system (DIRS 103821-Napier et al. 1988, all) was used to calculate annual average atmospheric dispersion factors for radon released from the subsurface exhaust points and for noble gases released from the Waste Handling Building stack. The releases from the South Portal would be at ground level, while releases from the exhaust shafts on the ridge above the repository were modeled as 60-meter (200-foot) releases. Noble gas releases from the Waste Handling Building would be from a 60-meter (200-foot) stack, also modeled as an elevated release. Table G-51 lists the atmospheric dispersion factors for the radon and krypton-85 release points at the site that incorporate the release distribution data in Table G-50. The radon dispersion factors would vary among combinations of operating mode and project phase because of the differences in release point contributions noted in Table G-50. Population dispersion factors have been normalized to be independent of the population size. The population distribution data in Tables G-48 and G-49 can be used with the atmospheric dispersion factors to calculate population-weighted dispersion factors for public and noninvolved worker populations, from which collective doses can be calculated.

G.2.3 RADIOLOGICAL SOURCE TERMS

There would be two distinctly different types and sources of radionuclides released to the air from activities at the repository. Naturally occurring radon-222 and its radioactive decay products would be released from the subsurface facility during all phases as the repository ventilation system removed airborne particulates from development operations and exhausted air heated by the emplaced materials. Radioactive noble gases would be released from commercial spent nuclear fuel during handling and transfer operations in the surface facilities during the operation and monitoring phase. Section G.2.3.1 discusses the releases of radon-222 and radon decay products. Section G.2.3.2 discusses the releases of radioactive noble gases from commercial spent nuclear fuel.

Table G-50. Distribution (percent) of repository subsurface exhaust ventilation air.[a,b]

Operating mode, release point	Construction	Concurrent development and emplacement	Emplacement only; and monitoring	Closure
Proposed Action: higher-temperature				
South Portal	100	30	NA[c]	NA
Exhaust Shaft 1	NA	40	33.3	33.3
Exhaust Shaft 2	NA	20	33.3	33.3
Exhaust Shaft 3	NA	10	33.3	33.3
Proposed Action: lower- temperature maximum ventilation; Inventory Modules 1 and 2: higher-temperature				
South Portal	100	30	NA	NA
Exhaust Shaft 1	NA	20	16.7	16.7
Exhaust Shaft 2	NA	15	16.7	16.7
Exhaust Shaft 3	NA	10	16.7	16.7
Exhaust Shaft 4	NA	10	16.7	16.7
Exhaust Shaft 5	NA	10	16.7	16.7
Exhaust Shaft 6	NA	5	16.7	16.7
Proposed Action: lower-temperature maximum waste package spacing; Inventory Modules 1 and 2: lower-temperature operating mode				
South Portal	100	20	NA	NA
Exhaust Shaft 1	NA	10	11.1	11.1
Exhaust Shaft 2	NA	10	11.1	11.1
Exhaust Shaft 3	NA	10	11.1	11.1
Exhaust Shaft 4	NA	10	11.1	11.1
Exhaust Shaft 5	NA	10	11.1	11.1
Exhaust Shaft 6	NA	5	11.1	11.1
Exhaust Shaft L1	NA	10	11.1	11.1
Exhaust Shaft L2	NA	10	11.1	11.1
Exhaust Shaft L3	NA	5	11.1	11.1

a. Sources: Derived from DIRS 153849-DOE (2001, pp. 2-139 to 2-147); DIRS 155515-Williams (2001, Part 1, pp. 6 to 7, Part 2, pp. 5 to 6).
b. Exhaust shaft releases are elevated; portal releases are ground-level.
c. NA = not applicable.

G.2.3.1 Release of Radon-222 and Radon Decay Products from the Subsurface Facility

In the subsurface facility the noble gas radon-222 would diffuse continually from the rock into the air of the repository drifts. Radioactive decay of the radon in the air of the drift would produce radon decay products, which would begin to come into equilibrium (having the same activity) with the radon-222 because their radioactive half-lives are much shorter than the 3.8-day half-life of radon-222. Key radionuclide members of the radon-222 decay chain are polonium-218 and polonium-214, with half-lives of 3.05 minutes and 164 microseconds, respectively. Exhaust ventilation would carry the radon-222 and the radon decay products from the repository.

The estimates of radon-222 and its decay product releases were based on concentration observations made in the Exploratory Studies Facility subsurface areas during site characterization and subsequent analyses of these data (DIRS 150246-CRWMS M&O 2000, all; DIRS 154176-CRWMS M&O 2000, all). These two reports have significantly expanded the available information on radon-222 flux into the repository, radon concentrations in the repository, and radon release from the repository.

Table G-51. Atmospheric dispersion factors (seconds per cubic meter) for potentially exposed individuals and populations.[a,b,c]

Operating mode, receptor	Receptor location	Construction	Operation and monitoring: Concurrent development and emplacement	Operation and monitoring: Emplacement only; and monitoring	Closure
Repository radon releases					
Proposed Action, higher-temperature					
Public MEI[d]	(e)	2.2×10^{-8}	1.1×10^{-8}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km[f] radius	4.8×10^{-9}	2.3×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.9×10^{-5}	1.8×10^{-8}	1.8×10^{-8}
Worker population	South Portal	3.1×10^{-5}	9.3×10^{-6}	1.8×10^{-8}	1.8×10^{-8}
Worker population	North Portal	2.7×10^{-7}	8.9×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	4.0×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Proposed Action: lower-temperature maximum ventilation; Inventory Modules 1 and 2: higher-temperature					
Public MEI	(e)	2.2×10^{-8}	1.1×10^{-8}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km radius	4.7×10^{-9}	2.3×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.9×10^{-5}	2.1×10^{-8}	2.1×10^{-8}
Worker population	South Portal	3.1×10^{-5}	9.3×10^{-6}	2.1×10^{-8}	2.1×10^{-8}
Worker population	North Portal	2.7×10^{-7}	9.0×10^{-8}	1.5×10^{-8}	1.5×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	4.0×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Proposed Action: lower-temperature maximum waste package spacing; Inventory Modules 1 and 2: lower-temperature					
Public MEI	(e)	2.2×10^{-8}	9.2×10^{-9}	6.0×10^{-9}	6.0×10^{-9}
Public population	80 km radius	4.8×10^{-9}	2.0×10^{-9}	1.3×10^{-9}	1.3×10^{-9}
Worker MEI	South Portal	6.2×10^{-5}	1.2×10^{-5}	2.9×10^{-8}	2.9×10^{-8}
Worker population	South Portal	3.1×10^{-5}	6.2×10^{-6}	2.9×10^{-8}	2.9×10^{-8}
Worker population	North Portal	2.7×10^{-7}	6.9×10^{-8}	2.1×10^{-8}	2.1×10^{-8}
Nevada Test Site worker population	50 km east-southeast	6.9×10^{-10}	3.5×10^{-10}	2.7×10^{-10}	2.7×10^{-10}
Waste Handling Building stack releases				Operations	
Public MEI	(e)			6.0×10^{-9}	
Public population	80 km radius			1.3×10^{-9}	
Worker MEI	North Portal			3.2×10^{-7}	
Worker population	North Portal			3.2×10^{-7}	
Worker MEI	South Portal			6.4×10^{-8}	
Worker population	South Portal			6.4×10^{-8}	

a. Numbers are rounded to two significant figures.
b. Includes contribution and distribution from all operating exhaust shafts and portals. Stack and exhaust shaft releases would be elevated; south portal releases would be ground-level.
c. Dispersion factors have been normalized for populations. Multiply times the population to get the population dispersion factor.
d. MEI = maximally exposed individual.
e. Located at the southern boundary of the land withdrawal area.
f. km = kilometer; to convert kilometers to miles, multiply by 0.62137.

The radon-222 flux into the repository would depend on many different parameters. One such parameter is the repository air pressure, which would depend on the ventilation flow rate. Air pressure, radon flux, and radon concentration were estimated for the portion of the repository ventilated by one exhaust shaft for the higher-temperature repository operating mode (DIRS 154176-CRWMS M&O 2000, pp. 18 to 25). These characteristics were assumed to be applicable for each area of the repository ventilated by an

exhaust shaft, so the higher-temperature operating mode—with three exhaust shafts—would have three areas with these exhaust characteristics. Similar assumptions were made for the lower-temperature operating mode where the repository would be ventilated by six to nine exhaust shafts. The analysis modeled a fully excavated, functioning repository, but these characteristics would be representative of all repository phases. This assumption might tend to overestimate the actual release of radon from the repository.

From the above information, average radon flux and radon release values were determined for three major types of repository excavation. The distinctions, which are based on the diameter of the excavation, include 7.6-meter (25-foot) and similar diameter excavations, typical of main drifts, ramps, and ventilation shafts; 5.5-meter (18-foot) and similar diameter excavations, typical of emplacement, standby, and observation drifts; and 2-meter (6.6-foot) and similar diameter excavations, typical of ventilation raises. The estimated average radon fluxes for these excavation types would be 35, 41, and 41 picocuries per square meter of exposed rock area per second, respectively. As noted above, these fluxes were assumed to apply to the respective diameter excavations in all repository areas. The estimated average activity of radon emanating per year per meter of the respective excavation types would be 0.021, 0.022, and 0.008 curie per meter per year. Information on the length and volume of repository excavations during the construction phase and during subsequent development is available for the range of operating modes analyzed (DIRS 150941-CRWMS M&O 2000, pp. 6-5 and 6-10; DIRS 155515-Williams 2001, Part 1, pp. 11 and 16, and Part 2, pp. 9 and 14). The analysis assumed that lengths and volumes would increase linearly over the project periods during which excavation took place, namely the 5 years of the construction phase and 22 years of development during the operations period at the beginning of the operation and monitoring phase.

The analysis assumed that, during the construction phase and development activities, all excavated areas of the repository except the 5.5-meter (18-foot) drifts (emplacement drifts, etc.) would be lined with concrete. This liner would be a barrier to radon diffusion into the repository, which would reduce radon flux by 50 percent (DIRS 152541-Ikenberry 2000, all). The analysis assumed the liners would be added linearly to applicable areas of the repository throughout the construction phase and the development period. The only exception would be a portion of the South Main Drift and ramp, which would not be lined with concrete until late in the development period. The analysis also assumed that the liners throughout the repository would be maintained during the preclosure period to prevent and seal fractures and maintain the reduction in radon flux for applicable repository areas.

Construction Phase

Repository excavation and radon releases would be very similar for the operating modes during the 5 years of the construction phase. The initial Exploratory Studies Facility excavated volume of about 420,000 cubic meters (550,000 cubic yards) would increase to 1.7 million to 2.1 million cubic meters (2.2 million to 2.7 million cubic yards) by the end of the construction phase. Most of the excavation during this phase would be for the 7.6-meter (25-foot) drifts and shafts.

Operation and Monitoring Phase

Operations Period. The operations period would last 24 years without aging, 50 years with aging. Development activities would take place during the first 22 years of operation and monitoring. During this period an additional 2.7 million to 6.8 million cubic meters (3.5 million to 8.9 million cubic yards) of repository volume would be excavated (DIRS 150941-CRWMS M&O 2000, p. 6-10; DIRS 155515-Williams 2001, Part 1, pp. 11 and 16 and Part 2, pp. 9 and 14). The total excavated volume would range from 4.3 million to 8.8 million cubic meters (5.6 million to 11.5 million cubic yards). During development activities a sizeable amount of the excavation would be of the 5.5-meter (18-foot) emplacement drifts and other 5.5-meter excavations. The maximum annual radon release would begin following the completion of

Table G-52 lists the estimated releases of radon-222 and radon decay products annually and by project phase.

Table G-52. Estimated radon-222 releases for repository activities under the Proposed Action.

Project phase or period and operating mode	Annual average radon release[b] (curies)	Maximum annual radon release[b,c] (curies)	Total radon release[b] (curies)	Duration (years)
Total, all phases				
Higher-temperature	1,900		220,000	115
Lower-temperature	1,400 - 4,100		480,000 - 1,000,000	171 - 341
Construction Phase				
Higher-temperature	480	610	2,400	5
Lower-temperature	480 - 570	610 - 750	2,400 - 2,900	5
Operations period				
Higher-temperature	1,500	2,100	36,000	24
Lower-temperature	2,100 - 3,800	3,000 - 4,600	50,000 - 190,000	24, 50
Monitoring period				
Higher-temperature	2,100	2,100	160,000	76
Lower-temperature	1,000 - 4,600	1,000 - 4,600	410,000 - 940,000	99 - 300
Closure phase				
Higher-temperature	1,500	2,100	15,000	10
Lower-temperature	2,000 - 2,800	2,900 - 4,500	22,000 - 48,000	11 - 17
Retrieval scenario				
Higher-temperature[d]	2,100		30,000	14

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Includes radon-222 and radon decay products.
c. In general, these maximum annual values occur only for a single year. The major exception is for monitoring.
d. Retrieval is not part of the Proposed Action and only the higher-temperature operating mode was evaluated.

excavation, lasting the final 2 years (no aging) or 26 years (aging) of the operations period, and continue through the monitoring period. Highest annual average radon releases during operations would come from 6.4-meter (21-foot) waste package spacing of the lower-temperature operating mode, which would have the largest development and total excavated repository volume. Use of spent nuclear fuel aging would result in the highest operations period releases because of the additional 26 years of operations required.

Monitoring Period. No excavation would take place during the monitoring period, and the ventilation flowrate would remain constant, as would the radon release rate.

Monitoring and maintenance activities would last 76 years for the higher-temperature operating mode and up to 300 years of the lower-temperature operating mode. The highest total releases during monitoring would occur because of a 300-year monitoring period with forced ventilation. The lowest monitoring period release would occur if 250 years of natural ventilation were used following 50 years of forced ventilation. Releases during the monitoring period would account for 75 to 92 percent of the total radon released over the entire project duration.

Closure Phase

Annual releases of radon-222 and radon decay products during the closure phase would decrease linearly over the phase as the repository was gradually closed. The initial release rate would be the same as the monitoring period release rate and the ending release rate would equal that at the start of the operations period. The decrease in release rate from beginning to end would be 70 to 80 percent. Differences in the lengths of the closure phase (ranging from 10 to 17 years) would lead to additional differences in the total amount of radon released.

Retrieval

Only the higher-temperature repository operating mode was evaluated for a postulated retrieval scenario. Estimated releases would occur over a 14-year period of construction and retrieval operations. The 10-year planning period preceding retrieval was assumed to occur during the monitoring period and was not included in the evaluation. The annual release rate of radon-222 and its decay products would be the same as that for the monitoring period.

Inventory Modules 1 and 2

Releases of radon-222 and its decay products for Inventory Modules 1 and 2 were estimated using the same methods as those used for the Proposed Action. The major differences would be the larger repository volumes, which would result in larger releases of radon. In addition, the project duration would be longer under the Proposed Action, with 38 years required to complete operations (which would include 36 years of development), and a longer closure phase. Table G-53 lists estimated radon releases. Releases of radon would be higher for the inventory modules than for the Proposed Action in all cases.

Table G-53. Estimated radon-222 releases for repository activities for Inventory Modules 1 or 2.[a]

Project phase and operating mode	Annual average radon release[b] (curies)	Maximum annual radon release[b,c] (curies)	Total radon release[b] (curies)	Duration (years)
Total, all phases				
Higher-temperature	2,600		300,000	117
Lower-temperature	2,100 - 6,200		760,000 - 1,600,000	191 - 359
Construction phase				
Higher-temperature	480	610	2,400	5
Lower-temperature	560 - 570	730 - 750	2,800 - 2,900	5
Operations period				
Higher-temperature	2,000	3,200	78,000	38
Lower-temperature	2,800 - 5,100	4,500 - 7,400	110,000 - 260,000	38 or 51
Monitoring period				
Higher-temperature	3,200	3,200	200,000	62
Lower-temperature	1,500 - 7,400	1,500 - 7,400	610,000 - 1,400,000	112 - 300
Closure phase				
Higher-temperature	2,100	3,100	25,000	12
Lower-temperature	2,800 - 4,300	4,400 - 7,300	44,000 - 98,000	15 - 23

a. Numbers are rounded to two significant figures; totals might not equal sums of values due to rounding.
b. Includes radon-222 and radon decay products.
c. In general these maximum annual values would occur only for a single year. The major exception would be for monitoring.

G.2.3.2 Release of Radioactive Noble Gases from the Surface Facility

The unloading and handling of commercial spent nuclear fuel would produce the only routine emissions of manmade radioactive materials from repository facilities. No releases would occur as a result of emplacement activities. Shipping casks containing spent nuclear fuel would be opened in the transfer pool of the Waste Handling Building at the North Portal Operations Area. During spent nuclear fuel handling and transfer, radionuclides could be released from a small percentage of fuel elements with pinhole leaks in the fuel cladding; only noble gases would escape the pool and enter the ventilation system of the Waste Handling Building (DIRS 104508-CRWMS M&O 1999, p. 17). The largest release of radionuclides from surface facilities would be krypton-85, with about 2,600 curies released annually. Releases of other noble gas radionuclides would be very small, with estimated annual releases of about 0.0000010 curie of krypton-81, 0.000033 curie of radon-219, 0.059 curie of radon-220, 0.0000046 curie of radon-222, and even smaller (negligible) quantities of xenon-127 (DIRS 152010-CRWMS M&O 2000, p. 52). The same annual releases would occur for both the Proposed Action and for the inventory modules. Of these radionuclides, krypton-85 would be by far the largest and most important dose contributor, from releases totaling 61,000 curies for the Proposed Action and 97,000 curies for the inventory modules. All spent nuclear fuel and high-level radioactive waste in disposable canisters would be transferred from shipping casks to disposal containers in shielded rooms (hot cells) in the Waste Handling Building. Because all DOE material would be in sealed disposable canisters, no radionuclide releases from these materials would occur.

Releases of noble gases from the surface facility would be the same for all operating modes. These estimated releases were based on the following assumptions for commercial spent nuclear fuel (DIRS 104508-CRWMS M&O 1999, p. 17):

- Pressurized-water reactor burnup of about 40 gigawatt-days per metric ton of uranium with 3.7-percent enrichment and an average of 26 years decay
- Boiling-water reactor burnup of 32 gigawatt-days per metric ton of uranium with 3-percent enrichment and an average of 27 years decay
- A failure rate of 0.25 percent for fuel assemblies in the canisters, allowing gaseous radionuclides (isotopes of krypton, radon, and xenon) to escape
- Radionuclides other than noble gases (such as cobalt-60, cesium-137, and strontium-90) would not escape the transfer pool if released from fuel assemblies

G.2.3.3 Release from Waste Packages Prior to Repository Closure

DOE examined the potential for release of radionuclides from failed waste packages and failed spent nuclear fuel during the operation and monitoring phase and the closure phase to determine if this would be another source of manmade radionuclides during the repository project.

DOE considered the potential for failure of waste packages and spent nuclear fuel cladding in detail in evaluating the long-term performance of the repository (see Chapter 5 and Appendix I). Section 5.5.1 notes that more than 99 percent of the cladding on spent nuclear fuel would be intact at the time it was placed in waste packages and emplaced in the repository. Appendix I, Section I.2.4, discusses the early failure of waste packages, and notes that a small number of waste packages (zero to three) could undergo early failure caused by improper heat treatment of the outer lid closure weld. This analysis is conservative and does not account for the inner lid weld or the inner barrier lid weld. For preclosure activities, it is assumed that the inner lid and the inner barrier lid welds are in place. Therefore, no releases from waste packages during the preclosure period are expected.

G.2.4 DOSE CALCULATION METHODOLOGY

The previous three sections provided information on the location and distribution of potentially affected individuals and populations (Section G.2.1), atmospheric dispersion (Section G.2.2), and the type and quantity of radionuclides released to air (Section G.2.3) in the Yucca Mountain region. The analysis used these three types of information to estimate the radionuclide concentration in air (in picocuries of radionuclide per liter of air) at a specific location or for an area where there would be a potentially exposed population. The estimation of the radiation dose to exposed individuals or populations from concentrations of radionuclides in air used this information and published dose factors. This section describes the concentration-to-dose conversion factors that the analysis used to estimate radiation dose to members of the public and noninvolved workers from releases of radionuclides at the repository.

G.2.4.1 Dose to the Public

The analysis estimated doses to members of the public using screening dose factors from the National Council on Radiation Protection and Measurements (DIRS 101882-NCRP 1996, Volume I, pp. 113 and 125). Use of these factors results in a conservative (tending to overestimate) estimate of the dose that could be received). The analysis considered all exposure pathways, including inhalation, ingestion, and direct external radiation from radionuclides in the air and on the ground. For noble gases released from the Waste Handling Building, krypton-85 would be by far the most important and largest dose contributor. Only direct external exposure from radionuclides in the air would be a contributing exposure pathway. The analysis estimated the dose from krypton-85 by multiplying 1) the radionuclide activity released 2) the atmospheric dispersion factor at the exposure location and 3) the radionuclide-specific dose factor, with appropriate unit conversions (for example, seconds per year or liters per cubic meter) included. Table G-54 lists the screening dose factor for krypton-85 for members of the public. The analysis assumed that members of the public would be exposed for 8,000 hours per year (DIRS 101882-NCRP 1996, Volume I, p. 61). Results are presented in Chapter 4, Section 4.1.2.

Table G-54. Factors for estimating dose to the public and noninvolved workers per concentration of radionuclide in air (millirem per picocurie per liter per hour) for krypton-85 and radon-222.[a,b]

Radionuclide	Public	Noninvolved worker
Krypton-85[c]	0.0000013	0.0000013
Radon-222[d]	0.25[e]	0.00091[f]

a. Numbers are rounded to two significant figures.
b. Dose factors for radon-222 include dose contribution from decay products.
c. Source: DIRS 101882-NCRP (1996, p. 113); normalized from exposure time of 8,000 hours per year (p. 61).
d. Source: DIRS 101882-NCRP (1996, p. 125); normalized from exposure time of 8,000 hours per year (ground exposure is one-fourth of total exposure) (p. 61).
e. Includes all exposure pathways.
f. Includes only the inhalation and plume exposure pathways.

The short-lived decay products of radon-222 would account for essentially the entire dose from radon and its decay products, and the degree to which the decay products would reach equilibrium with radon-222 and their total activity are important considerations. At release from the repository, the estimated average fraction of equilibrium reached would be 0.22 (DIRS 154176-CRWMS M&O 2000, attachment 4), or 22 percent of the radon-222 activity. Once released to the atmosphere, the decay product activity would begin to build toward equilibrium with the parent radon-222 activity with a halftime of about one-half hour. It is difficult to estimate the equilibrium fraction in this dynamic outdoor environment. A typical outdoor radon equilibrium level is 60 percent (DIRS 155699-NCRP 1984, p. 25), with a lower degree of equilibrium closer to the source. Although this value is for a continuous radon source emanating from the ground over an essentially infinite area, DOE used it as a conservative estimate of the equilibrium fraction. The analysis used the average annual wind speed of 2.5 to 4.4 meters per second (5.6 to 9.8 miles per hour) (see Chapter 3, Section 3.1.2.2) to estimate the radon decay product equilibrium fraction at the location of members of the public. It used 3 meters per second (6.7 miles per hour) as representative. The transit time to the location of the maximally exposed individual at the southern boundary of the land withdrawal area would be less than 2 hours (0.08 day). At this location the estimated equilibrium fraction would be 0.5, so the radon decay product activity would be 50 percent of the radon released, with these radionuclides available to enter the exposure pathways. For the population within 80 kilometers (50 miles), the estimated equilibrium fraction would be 0.6, and the radon decay product activity would be 60 percent of the radon released, with these radionuclides available to enter the exposure pathways. These estimates do not include removal mechanisms such as the deposition of radon decay products, so they are conservative, tending to overestimate the actual dose that could be received.

The screening dose factors for radon-222 and its decay products indicate that direct external radiation from radionuclides deposited on the ground would account for about 40 percent of the dose. Ingestion of the radon decay products in foodstuffs and inadvertently consumed soil would account for about 60 percent of the dose. Inhalation and external irradiation from radionuclides in the air would be minor exposure pathways. The analysis estimated the dose from radon-222 and its decay products by multiplying the radon-222 activity released by the equilibrium factor by the atmospheric dispersion factor at the exposure location by the radionuclide-specific dose factor, with appropriate unit conversions included. Table G-54 lists the screening dose factors for radon-222 and its decay products for members of the public. Results are presented in Chapter 4, Section 4.1.2.

Dose to members of the public (and to noninvolved workers, described below) is calculated in the following manner using the information presented throughout Section G.2:

$$\text{dose (millirem per year)} = Q \times \chi/Q \times F \times DF \times t \times \text{(unit conversion factors)}$$

where Q = activity released (curies per year)

χ/Q = atmospheric dispersion factor (seconds per cubic meter)

F = equilibrium fraction for radon decay products at exposure location (unitless)

DF = dose factor from Table G-54

t = exposure time, in hours per year

Unit conversion factors used include liters per cubic meter, picocuries per curies, and seconds per year. Multiplying the activity release by the atmospheric dispersion factor by the equilibrium fraction, if applicable—with appropriate unit conversions—yields the radionuclide concentration in air at the point of exposure.

G.2.4.2 Dose to Noninvolved Workers

The analysis used the same krypton-85 screening dose factor described above to calculate doses to noninvolved workers because the exposure pathway is simple (air submersion only) and is the same as for members of the public. However, the radon-222 screening dose factor for involved workers is different from that used for the public, because noninvolved workers are exposed only through the inhalation and plume exposure pathways. The other exposure pathways are not applicable for noninvolved workers, namely the ground exposure and ingestion pathways. The ground exposure pathway was not included because site workers would not typically be in locations where decay products could build up for many years without being physically disturbed or washed away.

Section G.2.1 describes the location of the maximally exposed noninvolved worker in the South Portal Development Area. There would be no releases from the South Portal during the other project phases and atmospheric dispersion factors would be much smaller (greater dispersion and, therefore, lower resulting radiation dose). The estimated equilibrium fraction for Yucca Mountain noninvolved worker exposure would be 0.22, the same as that for ventilation air at the exhaust point, as described in Section G.2.4.1. Transit times from release to a noninvolved worker or noninvolved worker population would be short, ranging from less than 1 minute to about 30 minutes at wind speeds of 3 meters per second (6.7 miles per hour), and deposition of radon decay products would occur, so the increase toward equilibrium would be small. The estimated equilibrium fraction for noninvolved workers at the Nevada Test Site would be 0.5, because the transit time of about 5 hours (0.19 day) for the 50-kilometer (31-mile) distance would allow the radon decay products to reach a higher level of equilibrium.

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Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

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Appendix H

Potential Repository Accident Scenarios: Analytical Methods and Results

APPENDIX H. POTENTIAL REPOSITORY ACCIDENT SCENARIOS: ANALYTICAL METHODS AND RESULTS

This appendix has been moved to Volume IV of this EIS.

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APPENDIX I. ENVIRONMENTAL CONSEQUENCES OF LONG-TERM REPOSITORY PERFORMANCE

This appendix provides detailed supporting information on the calculation of the environmental consequences of long-term repository performance (postclosure, up to 1 million years). Chapter 5 summarizes these consequences for the Proposed Action, and Chapter 8, Section 8.3.1 summarizes the cumulative impacts of Inventory Modules 1 and 2.

Section I.1 introduces the bases for analysis of long-term performance. Section I.2 provides an overview of the use of computational models developed for the Total System Performance Assessment (TSPA) model, that was used for the analysis of long-term impacts to groundwater in this environmental impact statement (EIS). Section I.3 identifies and quantifies the inventory of waste constituents of concern for analysis of long-term performance. Section I.4 details the modeling extensions to the TSPA *nominal scenario* [Proposed Action inventory, reasonably maximally exposed individual (RMEI) location at approximately 18 kilometers, or 11 miles, downgradient of the potential repository, and no disruptive events other than seismic] developed to estimate potential impacts for expanded inventories. An estimate of how the impacts might change for locations beyond the RMEI location is also provided. Section I.5 provides detailed results for waterborne radioactive material impacts, while Section I.6 provides the same for waterborne chemically toxic material impacts. Section I.7 describes atmospheric radioactive material impacts. To aid readability, all the figures are placed at the end of the appendix.

HOW ARE THE TOTAL SYSTEM PERFORMANCE ASSESSMENT MODEL AND THIS EIS ANALYSIS RELATED?

The analysis of long-term performance for this EIS builds incrementally on the TSPA model.

This appendix is primarily concerned with those aspects of the EIS analysis of long-term performance that are incremental over the TSPA model. Only those parts of the analysis unique to this EIS are detailed in this appendix, and the text refers to the appropriate TSPA model documents for information on the bases of the analyses. Some aspects of the modeling detailed in the TSPA are repeated in this appendix in overview form to provide continuity and enhance understanding of the approach.

For a full understanding of all details of the analysis of long-term performance in this EIS, it is necessary to study not only this appendix but also the other TSPA model documents cited herein.

I.1 Introduction

This EIS analysis of postclosure impacts used and extended the modeling work performed for the Yucca Mountain site suitability evaluation that supports the site recommendation process. The EIS analysis relied on the GoldSim program computer simulation model (DIRS 151202-Golder Associates 2000, all) used by DOE to calculate radiological doses resulting from waterborne releases through the groundwater pathway.

Analysis of long-term performance for this EIS required several steps. The EIS analysis model started with the TSPA model, which was modified as discussed below. For this EIS the modeling (described in this appendix) was further expanded to evaluate the impacts for expanded waste inventories (see Section I.4). Additional calculations provided estimates of how the impacts would vary for two other distances [30 kilometers (19 miles) downgradient, and the discharge location that is 60 kilometers (37 miles) downgradient at Franklin Lake Playa (refer to Section I.4.5)], analysis of long-term groundwater impacts of chemically toxic materials, and estimates of atmospheric radiological doses to the local population.

The model used to evaluate long-term impacts of radioactive materials in the groundwater simulates the release and transport of radionuclides away from the repository into the unsaturated zone, through the unsaturated zone, and ultimately through the saturated zone to the accessible environment. Analysis of long-term performance depends greatly on the underlying process models necessary to provide thermal-hydrologic conditions, near-field geochemical conditions, unsaturated zone flow fields, and saturated zone flow fields as a function of time. Using these underlying process models involves multiple steps that must be performed sequentially before modeling of the overall system can begin.

Figure I-1 shows the general flow of information between data sources, process models, and the TSPA model. Several process-level computer models are identified in Figure I-1. Examples are the site- and drift-scale thermal hydrology model and the saturated zone flow and transport model. The process models are very large and complex computer software programs used in detailed studies to provide information to the TSPA model. These process models are generally where fundamental laboratory and field data are introduced into the modeling. The subsystem and abstracted models section of the figure encompasses those portions of the TSPA model that are modeled within the GoldSim program. Examples are the unsaturated zone flow fields and the biosphere dose conversion factors. These models are generally much simpler than the process models. They are constructed to represent the results of the more detailed process modeling studies. Often they are simple functions or tables of numbers. This is the process referred to as *abstraction*. It is necessary for some of these subsystem models to be quite complex, even extensive computer codes. The ultimate result sought from modeling long-term performance is a characterization of radiological dose to humans with respect to time, shown at the top of the TSPA section of the figure. This is accomplished by assessing behavior at intermediate points and "handing" off the results to the next subsystem in the primary release path.

ABSTRACTION

Abstraction is the distillation of the essential components of a process model into a suitable form for use in a TSPA. The distillation must retain the basic intrinsic form of the process model but does not usually require its original complexity. Model abstraction is usually necessary to maximize the use of limited computational resources while allowing a sufficient range of sensitivity and uncertainty analyses.

I.2 Total System Performance Assessment Methods and Models

DOE conducted analyses for this EIS to evaluate potential long-term impacts to human health from the release of radioactive materials from the Yucca Mountain Repository. The analyses were conducted in parallel with, but distinct from, the TSPA calculations for the site suitability evaluation. The methodologies and assumptions are detailed in the *Total System Performance Assessment for the Site Recommendation* (DIRS 153246-CRWMS M&O 2000, all), and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-CRWMS M&O 2001, all). These two versions of the model are referred to respectively here as the "Site Recommendation model" and the "Supplemental Science and Performance Analyses model." Note that the Supplemental Science and Performance Analyses model starts with the Site Recommendation model and includes incremental enhancements to several parts of the Site Recommendation model. Further changes were made to the model to meet distinct requirements of this EIS. These changes are discussed in more detail in Section I.4 and in DIRS 157307-BSC (2001, Enclosure 1). In summary, the changes are as follows:

- The biosphere dose conversion factors are based on the Reasonably Maximally Exposed Individual (RMEI) defined in 40 CFR 197.21.

impacts of chemically toxic materials, and estimates of atmospheric radiological doses to the local population.

The model used to evaluate long-term impacts of radioactive materials in the groundwater simulates the release and transport of radionuclides away from the repository into the unsaturated zone, through the unsaturated zone, and ultimately through the saturated zone to the accessible environment. Analysis of long-term performance depends greatly on the underlying process models necessary to provide thermal-hydrologic conditions, near-field geochemical conditions, unsaturated zone flow fields, and saturated zone flow fields as a function of time. Using these underlying process models involves multiple steps that must be performed sequentially before modeling of the overall system can begin.

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- The biosphere dose conversion factors are based on the Reasonably Maximally Exposed Individual (RMEI) defined in 40 CFR 197.21.

- The length of the saturated zone simulated in the performance-assessment model extends from the edge of the repository to where the principal flow path crosses north latitude 36 degrees 40 minutes 13.6661 seconds, as the point where the RMEI would reside. This location is approximately 2 kilometers (1.2 miles) north of the intersection of U.S. Route 95 and Nevada State Route 373, a location formerly known as "Lathrop Wells" and currently known as "Amargosa Valley," that is approximately 20 kilometers (12 miles) downgradient from the repository.

- The groundwater protection standard using an annual water usage of 3.7 million cubic meters per year (exactly 3,000 acre-feet per year) was used in calculating the gross-alpha activity, the total radium concentration, and the total organ dose. All other concentrations were calculated using the same water usage as the Site Recommendation and the Supplemental Science and Performance Analyses models.

- The analysis used the waste inventory that was presented in *Inventory Abstraction* (DIRS 154841-BSC 2001, all). The difference between this inventory and that used in the Site Recommendation and Supplemental Science and Performance Analyses models is that for analysis purposes, U.S. Navy spent nuclear fuel is conservatively modeled as commercial spent nuclear fuel (DIRS 152059-BSC 2001, all and DIRS 153849-DOE 2001, Section 4.2.6.3.9, p. 4-257) and not as DOE-owned spent nuclear fuel.

- Waste package corrosion for the calculations in this report was due to general corrosion independent of temperature.

- The process-level lower-temperature repository operating mode thermal-hydrologic results were corrected to include radiation heat transfer.

- The model was expanded to accommodate inventories other than that for the Proposed Action.

The TSPA is a comprehensive systems analysis in which models of appropriate levels of complexity represent all important features, events, and processes to predict the behavior of the system being analyzed and to compare this behavior to specified performance standards. In the case of the proposed Yucca Mountain Repository system, a TSPA must capture all of the important components of both the engineered and the natural barriers. In addition, the Yucca Mountain TSPA must evaluate the overall uncertainty in the prediction of waste containment and isolation, and the risks caused by the uncertainty in the individual component models and corresponding parameters.

The components of the Yucca Mountain Repository system include five major elements that the TSPA must evaluate for the nominal scenario:

- The natural environment unperturbed by the presence of underground openings or emplaced wastes

- Perturbations to the natural system caused by construction of the underground facilities, waste emplacement, and expected natural events (such as seismic behavior)

- The long-term degradation of the engineered components designed to contain the radioactive wastes

- The release of the radionuclides from the engineered containment system

- The migration of these radionuclides through the engineered and natural barriers to the biosphere and their potential uptake by people, leading to a radiation dose consequence

The analysis included models associated with such disruptive events as volcanism and human intrusion (drilling). Sections I.2.10 and I.2.11 provide an overview of the processes and the models used to represent these disruptive events.

The EIS analysis of long-term performance represents a "snapshot in time," and ongoing work will help refine that snapshot. In the meantime, DOE believes the results of this EIS analysis are conservative estimates, and that work currently in progress or planned will increase confidence in the overall modeling approach.

The calculations for the TSPA model and calculations for this EIS were performed within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and related parameters. In some cases, bounding conservative values were used where the available data did not support development of a realistic range. This appendix presents the results as time histories of annual radiological dose to an individual over 10,000 and 1 million years following repository closure. As noted above, the TSPA model implements some of the individual process models directly, while other process models run outside the TSPA model to produce *abstractions* in the form of data tables, response surfaces, or unit-response functions. The TSPA model provides a framework for incorporating these abstractions and integrating them with other subsystem models. This is done in a *Monte Carlo* simulation-based methodology to create multiple random combinations of the likely ranges of the parameter values related to the process models. Probabilistic performance of the entire waste-disposal system was computed in terms of radiological dose to individuals at selected distances from the repository.

MONTE CARLO METHOD: UNCERTAINTY

An analytical method that uses random sampling of parameter values available for input into numerical models as a means of approximating the uncertainty in the process being modeled. A Monte Carlo simulation comprises many individual runs of the complete calculation using different values for the parameters of interest as sampled from a probability distribution. A different outcome for each individual calculation and each individual run of the calculation is called a *realization* (DIRS 153246-CRWMS M&O 2000, p. A-55).

The methodology for analysis of long-term performance for this EIS draws on the extensive analyses performed in support of the TSPA model. Most of the process models (and their abstractions) developed for the TSPA model were used directly in the analyses described in this appendix. Components that were modified to account for the additional analyses considered in this EIS are emphasized in this appendix. However, for continuity, the sections that follow include a general overview of all the elements of the TSPA model.

I.2.1 FEATURES, EVENTS, AND PROCESSES

The first step in the TSPA is to decide which representations of possible future states of the proposed repository (scenario classes and scenarios) are sufficiently important to warrant quantitative analysis. The TSPA model can analyze only a relatively small number of the essentially infinite combinations of features, events, and processes that could affect the system. It is important, therefore, that the scenarios chosen for analysis provide a sound basis for evaluating the performance of the repository. Specifically, the chosen scenarios must be representative of the conditions of greatest relevance to forecasting the long-term behavior of the system.

The first step in developing scenarios is to make an exhaustive list of features, events, and processes that could apply to the repository system. The initial list is developed using a number of resources:

- Lists previously compiled by other organizations on an international scale (such as the Nuclear Energy Agency of the Organization for Economic Cooperation and Development)
- Lists compiled during earlier stages of site exploration
- Lists developed by experts from the Yucca Mountain Project and outside consultants

The starting list is subjected to a comprehensive screening process. Features, events, and processes are screened from the list based on several criteria:

- Obvious inapplicability to the specific site (for example, the starting list included processes that occur only in salt, a rock type known to be not present at Yucca Mountain).
- Very low probability of occurrence (for example, meteorite impact)
- Very low consequence to the closed repository (for example, an airplane crash)
- Exclusion by regulatory direction (for example, deliberate human intrusion)

FEATURES, EVENTS, AND PROCESSES

Features are physical parts of the system important to how the system could perform. Examples include the Ghost Dance Fault and the Topopah Spring stratigraphic unit.

Events are occurrences in time that can affect the performance or behavior of the system. Events tend to happen in short periods in comparison to the period of concern, and they tend to occur at unpredictable times. Examples include a volcanic intrusion or a human intrusion by drilling.

Processes are physical and chemical changes that occur over long periods, tend to be 100-percent likely to occur, and are predictable. Examples include corrosion of the metals in the waste package and dissolution of waste form materials after exposure to water.

The remaining features, events, and processes are combined in scenarios that incorporate sequences of events and processes in the presence of features. The three main scenarios evaluated are:

- Nominal scenario (generally undisturbed performance with only seismic events)
- Volcanism scenario (eruption through the repository or intrusion of igneous material into the repository)
- Inadvertent human intrusion scenario.

When the scenarios described above were formed from the Features, Events, and Processes retained after screening, the focus was on the 10,000-year compliance period. Therefore in the screening documentation the reliance on a limit of 10,000-years was sometimes expressed. This EIS is charged by 40 CFR Part 197 with the task of reporting the peak dose values whenever they occur during the period of geologic stability. As can be seen by the results in this EIS, the peaks occur at times considerably longer than 10,000 years and it was necessary to carry out the analysis for 1 million years in order to establish the peak dose. Because the TSPA model used to generate all the results in the EIS is the same model that resulted from the Features, Events, and Processes screening it is important to explore the possible effect of the use of a 10,000 limit when screening Features, Events, and Processes. The following discussions are provided by the Features, Events, and Processes screening staff for that purpose (DIRS 155937-Freeze 2001, all). In addition to the discussions from the DIRS 155937-Freeze (2001, all) document there is also a short discussion of seismic Features, Events, and Processes. For a comprehensive discussion of all the Features, Events, and Processes the reader is referred to the Features, Events, and Processes database documentation (DIRS 154365-Freeze, Brodsky, and Swift 2001, all).

Note that in numbers given in the headings or text of Sections I.2.1.1 through I.2.1.7 (in the form "FEP No. X.X.X.X.X") refer to an index number from the Features, Events, and Processes database (DIRS 154365-Freeze, Brodsky, and Swift 2001, all).

I.2.1.1 Tectonic Activity (FEP No. 1.2.01.01.00)

The current strain rate is indicated by DIRS 118952-Savage, Svarc, and Prescott (1999, p. 17627) as less than 2 millimeters per year (0.08 inch per year) and is reflected in local slip rates of between 0.001 and 0.03 millimeters per year (0.0004 and 0.001 inches per year). At the highest rate, the total slip after 10,000 years would be on the order of 0.010 to 0.3 meters (0.03 to 1 foot), but after 1 million years could be on the order of 1 to 30 meters (3.3 to 98 feet). The increased rates of tectonic and igneous activity in the geologic past (and leading to the 30-meter value) were associated with greater crustal strain rates than exist currently. In particular, DIRS 118942-Fridrich (1999, all) indicate extension of the Crater Flat structural basin to have been on the order of 18 to 40 percent between about 12.6 and 11.6 million years ago during the major pulse of extension, with the rate of extension declining exponentially since 11.6 million years ago. From the late Quaternary through the present, the rate of extension is less than 1 percent of the initial rate. These studies suggest that crustal extension rates are likely to vary insignificantly or to decrease with time. As a consequence, assumption of the existing tectonic setting and strain rates for periods out to 1 million years, for purposes of the EIS, is reasonable, although quantification of associated displacements would exhibit a time-dependent increase in uncertainty.

The median probability for exceeding fault displacements greater than 3 meters (10 feet) on the Solitario Canyon Fault is approximately 0.0001 in 10,000 years, and the median and mean probability for fault displacement on intrablock faults of 2 meters (6.6 feet) or greater is less than 0.0001 in 10,000 years (DIRS 100354-USGS 1998, all). The projected values assume that the tectonic strain rate is either equal to or less than the existing strain rate. Projection and use of these displacements for a 1-million-year time frame is appropriate, but is accompanied with an increase in uncertainty in the probable displacement value.

Based on the repository design, the drifts could accommodate as much as 2 meters (6.6 feet) of vertical displacement on intrablock faults before waste package shearing conditions could occur and, with the use of set-backs, at least 3 meters (10 feet) of offset could be accommodated in the Solitario Canyon Fault, and possibly more if distributed faulting is considered. Hypothetical models at the mountain-scale also suggest that flow in fault zones and fractures would not be significantly affected by displacement of as much as 10 meters (33 feet). The tolerance values are not time-dependent. The projected total slip values at 1 million years (1 to 30 meters, or 3.3 to 98 feet) are of the same order of magnitude as the tolerance limit (1 to 10 meters, or 3.3 to 33 feet).

Because the tolerance values are the same order of magnitude as the projected total slip, and because the tectonic setting and history of the site suggest that strain rates will either vary insignificantly or decrease, the assumptions and models in the TSPA related to tectonic activity should be reasonable and applicable for the 1-million-year time span as well.

I.2.1.2 Erosion/Denudation (FEP No. 1.2.07.01.00)

Erosion is a process that is expected to be ongoing at Yucca Mountain. The maximum erosion over 10,000 years is expected to be less than 10 centimeters (3.9 inches) (DIRS 100520-YMP 1993, p. 55), which is within the range of existing surface irregularities.

After 1 million years the maximum total erosion would be 10 meters (33 feet), assuming the erosion rate estimated for the next 10,000 years remained constant for the next 1 million years. This maximum value is far less than the amount required to expose waste at the land surface, and possible effects would therefore be limited to changes in infiltration and flow in the unsaturated zone. Local changes of as much as 10 meters would represent a small change relative to the hundreds of meters (thousands of feet) of topographic variability already incorporated in the infiltration model used to calculate flow in the unsaturated zone. The effects of erosion on infiltration are therefore considered negligible. Erosion due to normal surface processes at Yucca Mountain is therefore excluded from the 1 million-year analyses.

Future climate projections extending to 10,000 years (DIRS 136368-USGS 2000, all; DIRS 153038-CRWMS 2000, all) indicate that, although the climate is expected to evolve to a cooler, wetter climate, conditions will be that of a glacial transition or glacial-type climate. As a result, direct glacial erosion and transport is not considered a credible event. Therefore, glacial erosion is excluded on the basis of low probability.

The effects of erosion processes on how radionuclides might accumulate in soils and subsequently enter the biosphere are included (DIRS 136281-CRWMS M&O 2000, Section 6.1.1) for the post-10,000-year period. The effects of erosional processes in the biosphere are considered in an Analysis Model Report titled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (DIRS 136281-CRWMS M&O 2000, all) and are considered in *Total System Performance Assessment for the Site Recommendation* (DIRS 153246-CRWMS M&O 2000, Sections 3.9 and 3.10) as part of the peak dose calculations.

I.2.1.3 Periglacial Effects (FEP No. 1.3.04.00.00)

This process refers to climate conditions that could produce a cold, but glacier-free, environment. Results of such a climate could include permafrost (permanently frozen ground). Some consequences of such a condition identified in the secondary Features, Events, and Processes are enhanced erosion due to the freeze/thaw cycle and the trapping of gases in or near the proposed repository.

Global climate change was addressed in the TSPA using a climate model based on paleoclimate information. That is, the record of climate changes in the past was used to predict changes in climate for the future. Because the geologic record indicates that climatic conditions during the Quaternary period (the past 1.6 million years) at no time resulted in plant communities at Yucca Mountain that are consistent with periglacial conditions (DIRS 136281-CRWMS M&O 2000, Section 4.2.4), this process has been excluded on the basis of low probability.

Future climates are described in terms of discrete climate states that are used to approximate continuous variations in climate. The effects of seasonality are included in the climate model by using climate analogs with specific seasonal meteorological records. More specific information about the methods used to predict future climate change and the findings for the climate model is provided in DIRS 136368-USGS (2000, Section 6). Climate modeling is incorporated in the TSPA through the unsaturated zone flow fields, which have different surface-water infiltration as a result of different climates. A description of the modeling methods used for infiltration and how infiltration is affected by climate is in DIRS 136368-USGS (2000, Section 6).

Potential future climate conditions at Yucca Mountain were analyzed in two Analysis Model Reports: *Future Climate Analyses* (DIRS 136368-USGS 2000, all) and *Documentation of Million-Year TSPA* (DIRS 153038-CRWMS 2000, all). The climate at Yucca Mountain for the next 10,000 years is treated as a sequence of three climate states: modern (interglacial) climate for 400 to 600 years, monsoon climate for 900 to 1,400 years, and glacial-transition (intermediate) climate for the balance of the 10,000-year period. The glacial-transition (intermediate) climate occurs either preceding or following the colder, wetter full glacial climate states. Three additional full-glacial climate states are specified during the longer period of 1 million years, with different climate stages synchronized with the earth orbital clock. Full-glacial stages would encompass about 21 percent of the time over the next 1 million years. The intermediate climate would be the dominant climate for the next 1 million years.

I.2.1.4 Glacial and Ice Sheet Effects (FEP No. 1.3.05.00.00)

This process refers to the local effects of glaciers and ice sheets. Paleoclimate records indicate that glaciers and ice sheets have not occurred at Yucca Mountain at any time in the past (DIRS 136368-USGS 2000, Section 6.2). The closest alpine glaciers to Yucca Mountain during the Pleistocene were in the Sierra Nevada of California and possibly the Spring Mountains in Nevada (DIRS 151945-CRWMS M&O 2000, Section 4.2.3.3.6), too far from Yucca Mountain to have any effect on site geomorphology or hydrology. Given the relatively low elevation of Yucca Mountain, there is no credible mechanism by which a glacier could form at the site over the next 10,000 years, and there is no evidence to suggest formation at Yucca Mountain in the next 1 million years. Therefore, this process is excluded on the basis of low probability. Note, however, that the regional climatic effects of ice sheets that might form farther north are included based on a change in climate states.

I.2.1.5 Hydrostatic Pressure on Container (FEP No. 2.1.07.04.00)

A repository at Yucca Mountain would emplace waste above the water table in a fractured, porous medium. Thus, the pressure on the waste package is approximately atmospheric under present conditions. Possible changes in the elevation of the water table due to climate change and tectonic processes have been evaluated (DIRS 153931-CRWMS M&O 2001, Sections 6.2.11 and 6.2.8; DIRS 154826-BSC 2001, Section 6.7.6), and water table fluctuations due to climate change are included in the TSPA model. Even under the wettest future climate states, however, the highest elevation of the water table would be far below the emplacement drifts, and hydrostatic pressure effects on the packages are therefore excluded on the basis of low probability for both 10,000-year and 1-million-year analyses.

I.2.1.6 Soil and Sediment Transport (FEP No. 2.3.02.03.00)

Transport of soil and sediments in the biosphere is discussed in the Analysis Model Reports titled *Evaluate Soil/Radionuclide Removal by Erosion and Leaching* (DIRS 136281-CRWMS M&O 2000, all) and *Nominal Performance Biosphere Dose Conversion Factor Analysis* (DIRS 152539-CRWMS M&O 2001, all). The results of these analyses are used in Sections 3.9 and 3.10 of the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000). Aeolian and fluvial transport of contaminated volcanic ash has been indirectly included in the TSPA–Site Recommendation igneous disruption scenario through the use of a wind direction fixed toward the critical group for all hypothetical eruptions. As described in Section 3.10 of TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000), use of a fixed wind direction compensates for the lack of an explicit model for sediment transport following ash deposition by ensuring that all eruptions would result in the deposition of contaminated ash at the location of the critical group, regardless of the wind direction at the time of the event. The TSPA–Site Recommendation calculations include the probability of eruptive events extending past the 10,000-year regulatory period to calculate peak dose.

Paleoclimate records indicate that glaciers and ice sheets have not occurred at Yucca Mountain at any time in the past (DIRS 136368-USGS 2000, Section 6.2). The closest alpine glaciers to Yucca Mountain during the Pleistocene were in the Sierra Nevada of California and possibly the Spring Mountains in Nevada (DIRS 151945-CRWMS M&O 2000, Section 4.2.3.3.6), too far from Yucca Mountain to have any effect on site geomorphology or hydrology. Given the relatively low elevation of Yucca Mountain, there is no credible mechanism by which a glacier could form at the site within the time frames considered. Therefore, glacial transport of soil and sediments is not considered credible and this process is excluded on the basis of low probability.

I.2.1.7 Seismic Damage to Waste Packages

This discussion refers to the following Features, Events, and Processes:

- Seismic vibration causes container failure (FEP No. 1.2.03.02.00)
- Mechanical impact on waste container and drip shield (FEP No. 2.1.03.07.00)
- Effects and degradation of drip shield (FEP No. 2.1.06.06.00)
- Rockfall – large block (FEP No. 2.1.07.01.00)
- Mechanical degradation or collapse of drift (FEP No. 2.1.07.02.00)

These events all have to do with possible damage to the waste packages or drip shields either directly or indirectly (for example, rock fall) due to seismic events. In the Features, Events, and Processes screening these events were screened out for low consequence because up to 10,000 years the waste packages remain essentially intact (see detailed results in Section I.5) and possess their original design strength. Because the packages are designed to withstand seismic events that are of sufficient likelihood during the 10,000-year period, it follows that a low-consequence screening for the 10,000-year period is justified.

The analysis for the million-year period extended the screening of seismic damage to waste packages throughout that time. This was an analytical assumption based on using the best data and models available for the Final EIS. No quantitative analysis was performed to determine when a waste package might degrade to the point where it could be damaged by a seismic event. However, it is reasonable to expect that peak dose estimates would likely have been higher (by an unknown amount) if the analysis accounted for potential seismic damage of degraded waste packages hundreds of thousands of years into the future.

I.2.2 UNSATURATED ZONE FLOW

Changes in climate over time provide a range of conditions that determine how much water could fall onto and infiltrate the ground surface. Based on current scientific understanding, the current climate is estimated to be the driest that the Yucca Mountain vicinity will ever experience. All future climates were assumed similar to current conditions or wetter than current conditions. The *climate* model provides a forecast of future climates based on information about past patterns of climates (DIRS 153246-CRWMS M&O 2000, p. 3-38 to 3-42). This is generally accepted as a valid approach because climate is known to be cyclical and largely dependent on repeating patterns of earth orbit and spin. The model represents future climate shifts as a series of instant changes. During the first 10,000 years, there are three changes, in order of increasing wetness, from present-day to a monsoon and then to a glacial-transition climate. Between 10,000 years and 1 million years there are 45 changes between six climate states incorporated in the TSPA model (DIRS 153246-CRWMS M&O 2000, p. 3-38):

CLIMATE CHANGE

The analysis of long-term performance considered six climate states. Many changes in climate states occur in the simulation over a 1-million-year period after closure. The times of change are keyed to known past cycles for the previous million years as determined by paleoclimatology studies. (DIRS 153246-CRWMS M&O 2000, Figure 3.2-16, p. F3-24).

- Interglacial Climate (same as present day)
- Intermediate Climate (same as the Glacial-transition)
- Intermediate/Monsoon Climate
- Three stages of Glacial Climate of varying infiltration rates

Precipitation that is not returned to the atmosphere by evaporation or transpiration enters the unsaturated zone flow system. Water infiltration is affected by a number of factors related to climate, such as an increase or decrease in vegetation on the ground surface, total precipitation, air temperature, and runoff. The *infiltration* model uses data collected from studies of surface infiltration in the Yucca Mountain region (DIRS 155950-BSC 2001, Section 3.2.2). It treats infiltration as variable in the region, with more occurring along the crest of Yucca Mountain than along its base. The results of the climate model affect assumed infiltration rates. For each climate, there is a set of three infiltration rates (high, medium, low) and associated probabilities. This forms a discrete distribution that is sampled in the probabilistic modeling. The sampled ranges are described in Tables I-1 and I-2. Whenever a particular climate state is in effect, the associated infiltration rate distribution is sampled for each realization of the simulation.

Table I-1. Average net infiltration rates (millimeters per year) over the unsaturated zone flow and transport model domain for the present-day, monsoon, and glacial transition climate states.[a,b]

Climate	Lower bound	Mean	Upper bound
Present day	1.3	4.6	11.1
Monsoon	4.6	12.2	19.8
Glacial transition	2.5	17.8	33.0

a. Adapted from DIRS 155950-BSC (2001, Table 3.3.2-1).
b. To convert from millimeter per year to inch per year, multiply by 0.03937.

Table I-2. Average net infiltration rates (millimeters per year) over the unsaturated zone flow and transport model domain for full-glacial climate states.[a,b]

Climate	Lower bound	Mean	Upper bound
Glacial, Stage 8/10	33.0[c] (36.0[d])	87.9	151.0
Glacial, Stage 6/16	24.4	87.9	151.0
Glacial, Stage 4	12.9	24.4	87.9

a. Adapted from DIRS 155950-BSC (2001, Table 3.3.2-3).
b. To convert from millimeter per year to inch per year, multiply by 0.03937.
c. Derived using upper-bound intermediate climate meteorological station data (DIRS 155950-BSC 2001, Tables 3.3.1-5, 3.3.1-6).
d. Derived using alternate Stage 6/16 meteorological station data (DIRS 155950-BSC 2001, Tables 3.3.1-5, 3.3.1-6).

Water generally moves downward in the rock matrix and in rock fractures. The rock mass at Yucca Mountain is composed of volcanic rock that is fractured to varying degrees because of contraction during cooling of the original, nearly molten rock and because of extensive faulting in the area. Water flowing in the fractures moves much more rapidly than water moving through the matrix. At some locations, water might collect in locally saturated zones (*perched water*) or might be laterally diverted because of differing rock properties at rock layer interfaces. The overall unsaturated flow system is heterogeneous, and the locations of flow paths, velocities, and volumes of groundwater flowing along these paths are likely to change many times over the life of the repository system. The *mountain-scale unsaturated zone flow* model assumes constant flow over a specific period (taken from the infiltration model) and generates three-dimensional flow fields for three different infiltration boundary conditions, the six different climates described above, and several values of rock properties (DIRS 153246-CRWMS M&O 2000, pp. 3-29 and 3-41). The model is an isothermal model; thermal effects can be neglected because flow would be strongly perturbed only by heat near the emplacement drifts and at early times (DIRS 153246-CRWMS M&O 2000, p. 3-31). The influence of heat near the drifts is dealt with in the thermal hydrology models discussed below. The flow fields from the mountain-scale unsaturated zone flow model are the abstractions that are utilized by the TSPA model while the system model is running. The TSPA model simply switches to the correct flow field for the sampled infiltration rate, as dictated by the current climate state and sampling of the infiltration rate range.

After water returns to the repository walls, it would drip into the repository. The number of seeps that would occur and the amount of water that would be available to drip would be restricted by the low rate at which water flows through Yucca Mountain, which is in a semiarid area. Drips would occur only if the hydrologic properties of the rock mass caused the water to concentrate enough to feed a seep. Over time, the number and locations of seeps would increase or decrease, corresponding to increased or decreased infiltration based on changing climate conditions. The *seepage flow* model calculates the amount of seepage that could occur based on input from the unsaturated zone flow model (DIRS 155950-BSC 2001, Section 4.3). The basic conceptual model for seepage suggests that openings in unsaturated rock act as capillary barriers and divert water around them. For seepage to occur in the conceptual model, the rock pores at the drift wall would have to be locally saturated. Drift walls could become locally saturated by either disturbance to the flow field caused by the drift opening or variability in the permeability field that created channeled flow and local ponding. Of the two reasons, the variability effect is more important. Drift-scale flow calculations made with uniform hydrologic properties suggest that seepage would not occur at expected percolation fluxes. However, calculations that include permeability variations do estimate seepage, with the amount depending on the hydrologic properties and the incoming percolation flux. The seepage abstraction is based on extensive modeling calibrated by measurements from onsite testing in the Exploratory Studies Facility (DIRS 153246-CRWMS M&O 2000, pp. 3-35 to 3-36, and DIRS 155950-BSC 2001, Section 4.3.1.5). The seepage abstraction includes probability distributions for the fraction of waste packages encountering seepage and the seep flow rate, accounting for parameter uncertainty, spatial variability, and other effects, such as focusing (DIRS 155950-BSC 2001, Section 4.3.2), episodicity (DIRS 155950-BSC 2001, Section 4.3.5), rock bolts (DIRS 155950-BSC 2001, Section 4.3.3), drift degradation (DIRS 155950-BSC 2001, Section 4.3.4) and coupled processes (DIRS 155950-BSC 2001, Sections 4.3.5 through 4.3.7). All of these parameters are input as uncertainty distributions that are sampled in the probabilistic modeling.

I.2.3 ENGINEERED BARRIER SYSTEM ENVIRONMENTS

Engineered barrier system environments refer to the thermodynamic and chemical environments in the emplacement drifts. These environments control processes that affect the components of the engineered barrier system (such as the drip shields, waste packages, and waste forms). The environmental characteristics of importance are the degradation of the drift (including rock fall into the drift), temperature, relative humidity, liquid saturation, pH, liquid composition, and gas composition. Thermal effects on flow and chemistry outside the drifts are also important because they affect the amount and composition of water and gas entering the drifts. The engineered barrier system environments are important to long-term repository performance because they would help determine degradation rates of components, quantities and species of mobilized radionuclides, transport of radionuclides through the drift into the unsaturated zone, and movement of fluids into the unsaturated zone.

The *drift degradation model* describes the deterioration of the rock mass surrounding the repository emplacement drifts. Deterioration would occur by failure of fractures that bound blocks of rock at the drift walls and the resultant falling of those blocks into the drift. The deterioration is described in terms of key block analysis (DIRS 153246-CRWMS M&O 2000, pp. 3-43), which is a tool used for the following purposes:

- Provide a statistical description of block sizes formed by fractures around the emplacement drifts
- Estimate changes in drift profiles due to fallen blocks of rock
- Provide an estimate of the time required for significant drift deterioration to occur.

Key blocks would be formed by the intersection of three or more fracture planes with the excavation. Key blocks could become dislodged and fall because of seismic effects. A detailed analysis, based on observation and testing, was used to develop an abstraction of block failures and rockfalls. The abstraction is in the form of tables of numbers and volumes of blocks falling per unit length of emplacement drift as a function of time due to seismic and other effects.

Within the TSPA model, most engineered system calculations were performed for a limited number of waste package locations. In the model, each of these locations is representative of a group of waste packages with similar environmental characteristics. Radionuclide releases, for example, were calculated for a representative waste package and then scaled up by the number of failed waste packages in the group. Not all waste packages in a group would fail at the same time because additional variability is included in the waste package degradation calculation. The waste package groups (referred to as *bins*) are not based on physical location. Rather, the bins are based on infiltration patterns (that is, divided into categories of specific ranges of infiltration rate) and on waste type (that is, codisposal packages and commercial spent nuclear fuel packages) (DIRS 153246-CRWMS M&O 2000, Section 3.3.2).

The heat generated by the decay of nuclear materials in the repository would cause the temperature of the surrounding rock and waste packages to rise from the time of emplacement until a few hundred years after repository closure (DIRS 153246-CRWMS M&O 2000, Figure 3.3-9, p. F3-33). The water and gas in the heated rock would be driven away from the repository during this period, referred to in this EIS as the *thermal pulse*. The thermal output of the materials would decrease with time; eventually, the rock would return to its original temperature, and the water and gas would flow back toward the repository. The *multi-scale thermal hydrology model* is used to study the processes that would govern the temperature, relative humidity, liquid saturation, liquid flow rate, liquid evaporation rate, and thermal effects on seepage. Drift-scale modeling includes coupling of drift-scale processes with mountain-scale processes to account for effects such as faster cooling of waste packages near the edge of the repository, as compared to waste packages near the center. A multi-scale modeling and abstraction method was developed to couple drift-scale processes with mountain-scale processes (DIRS 153246-CRWMS M&O 2000, pp. 3-56 to 3-58, and DIRS 155950-BSC 2001, Section 5.3.1). In addition, a coupled *thermal-hydrology-chemistry model* was developed to study the coupled effects on the heat, flow and chemistry of the system (DIRS 153246-CRWMS M&O 2000, p. F3-33). The results of these detailed modeling studies are abstracted as response surfaces of temperature, humidity, and liquid saturation.

The source term for transport of radionuclides from the proposed repository in the unsaturated zone and saturated zone water flow is the radionuclide flux from inside the drifts to the unsaturated zone rock. That flux would be influenced by the in-drift engineered barrier system chemical environment. The *engineered barrier system geochemical environment models* (DIRS 153246-CRWMS M&O 2000, pp. 3-62 to 3-69 and DIRS 155950-BSC 2001, Sections 6.3.1 and 6.3.3) were used to study the changing composition of gas, water, colloids, and solids in the emplacement drifts under the perturbed conditions of the repository. Several submodels were integrated to provide detailed results and interpretations. The major composition changes would be caused by the thermal loading of the system and the emplacement of large masses of materials that can react with water and gas in the system. The system would continually change due to the heating and cooling cycle. Because the emplaced materials would be very different from the host rock, the entering water and gas would be altered by reaction with these materials. Emplaced materials could be an additional source of colloids that could affect how radionuclides were transported in the aqueous system. The engineered barrier system geochemical environment models produce detailed results that are then abstracted for the following processes:

- Water and cement interactions
- Gas and water interactions
- Evaporation of water and condensation of vapor
- Salts precipitation and dissolution
- Microbial activity and effects
- Corrosion and degradation of engineered barrier system components

- Water and invert interactions
- Water and colloids interactions.

The abstractions were integrated into the TSPA model as chemistry lookup tables for various periods, parametric results, and sometimes enhancement or correction factors for other processes such as corrosion or transport (DIRS 153246-CRWMS M&O 2000, pp. 3-69 to 3-79 and DIRS 155950-BSC 2001, Sections 5.3.2.2 and 6.3.1.6).

The location of the seeps would depend to some extent on the natural conditions of the rock but also on the alterations caused by the construction of a repository. Alterations, such as increased fracturing, would be caused by mechanical processes related to drilling the drifts or by thermal heating and expansion of the drift walls. The alterations in the seepage could also be caused by chemical alterations occurring as the engineered materials dissolved in water and reprecipitated in the surrounding rock, closing the pores and fractures. The chemistry in the drift would change continually because of the complex interactions between the incoming water, circulating gas, and materials in the drift (for example, concrete from the liner or metals in the waste package). The changes in chemistry would be strongly influenced by heat during the thermal pulse.

The seepage would flow through the engineered barrier system along eight pathways. These pathways are (DIRS 155950-BSC 2001, Sections 8.2 and 8.3):

1. Seepage flux entering the drift—This would be the liquid flow into the engineered barrier system.

2. Flow through the drip shield—Liquid flux through the drip shield would begin after holes formed due to general corrosion.

3. Diversion around the drip shield—The portion of the flux that did not flow through the drip shield was assumed to bypass the invert and flow directly into the unsaturated zone.

4. Flow through the waste package—The fluid flow through the waste package would be based on the presence of holes due to general corrosion. The liquid flux through any holes in the waste package is calculated using a flux splitting algorithm that incorporates the fraction of the waste package or drip shield that has openings. This algorithm considers the projected patch area on a breached waste package or drip shield.

5. Flow diversion around the waste package—The portion of the flux that did not flow through the drip shield and onto the waste package was assumed to bypass the waste form and flow directly onto the invert.

6. Evaporation from the invert condensation underneath the drip shield—The magnitude of the evaporative flux from the invert would be based on the thermal-hydrologic abstraction.

7. Flow from the waste package to the invert—All flux from the waste package would flow to the invert, independent of breach location on the waste package. The presence of the emplacement pallet was ignored, and the waste package was assumed to be lying on the invert so a continuous liquid pathway for diffusive transport would exist at all times.

8. Flow through the invert into the unsaturated zone—Flow could be by advection or diffusion. The model accounts for sorption in the invert.

The model accounts for the evaporation of some of the liquid flux to the drip shield (DIRS 155950-BSC 2001, Section 8.3.1.3). The evaporation rate at the top of the drip shield would be bounded by the amount of heat available to vaporize water on the upper portion of the drip shield. This heat flow rate into the upper portion of the drip shield was used to determine the maximum volumetric flow rate of incoming seepage water that could be completely vaporized at this location.

I.2.4 WASTE PACKAGE AND DRIP SHIELD DEGRADATION

The radioactive waste placed in the proposed repository would be enclosed in a two-layer waste package. The layers would be of two different materials that would fail at different rates and from different mechanisms as they were exposed to various repository conditions. The outer layer would be a high-nickel alloy metal (Alloy-22) and the inner layer a stainless-steel alloy metal (316NG). To divert dripping water away from the waste package and thereby extend waste package life, a Titanium Grade 7 drip shield would be placed over the waste packages just prior to repository closure. The drip shield would divert water entering the drift from above preventing seep water from contacting the waste package. The *drip shield and waste package degradation models* were used to simulate the degradation of these components (DIRS 153246-CRWMS M&O 2000, pp. 3-79 to 3-91, DIRS 155950-BSC 2001, Section 7, and DIRS 157307-BSC 2001, Enclosure 1). Three main types of degradation were considered in the nominal scenario: humid-air general corrosion, aqueous general corrosion, and stress corrosion cracking. Two additional corrosion processes—microbially induced corrosion and thermal aging/phase instability—were considered to provide enhanced general corrosion on the waste package. General corrosion mechanisms would be conceptually similar for the drip shield and waste package, and were simulated using a common approach. Mechanical failure by rockfall was screened out of the model due to low consequence.

The primary models supplying input to the drip shield and waste package degradation abstractions are the thermal hydrology model and the in-drift geochemical abstraction model. Output from the degradation models is a time-dependent quantitative assessment of the drip shield and waste package degradation and failure. Results include the time to initial breach for the drip shield and the waste package; time to first breach of the waste package by stress corrosion crack failure; and the degree of drip shield and waste package failure as a function of time. The time of the first breach of the waste package would correspond to the start of waste form degradation in the breached package. The output also includes the uncertainty and spatial variation of the degradation information for each waste package and drip shield at different locations (described above as *bins*) within the potential repository. A recent reevaluation of potential early waste package failure mechanisms indicated that improper heat treatment of waste packages could lead to a gross failure of affected waste packages, although the probability of this occurrence is very low. Therefore, improper heat treatment of waste packages is now modeled in the current waste package degradation analysis (DIRS 155950-BSC 2001, Section 7.3.6). An analysis of manufacturing and testing led to a probability distribution for the number of packages that could fail from improper heat treatment of the Alloy-22 closure weld. The resulting distribution is listed in Table I-3. The distribution for waste package failures reflects a very conservative view, because it is assumed that if the outer weld was not properly heat treated the package would automatically fail, even though improper heat treatment would not necessarily result in failure, and the inner weld on the Alloy-22 and the inner stainless steel weld would probably remain intact. This distribution was sampled for each realization of the TSPA model and resulted in early failures of a very small number of waste packages in some of the realizations. This would result in very small releases during the first 10,000 years after closure.

The analysis in this EIS assessed the possible effects of waterborne chemically toxic materials. The analysis did not identify any organic materials as being present in sufficient quantities to be toxic. A screening process eliminated most other materials because they were not of concern for human health effects (see Section I.6.1). Some of the components of the high-nickel alloy (such as chromium, molybdenum, nickel, and vanadium) would be of sufficient quantity and possible toxicity to warrant

Table I-3. Poisson probabilities for improper heat treatment of waste packages.[a]

	Proposed Action		Inventory Module 1		Inventory Module 2	
Number of packages	Probability	Cumulative probability	Probability	Cumulative probability	Probability	Cumulative probability
0	0.76874	0.76874	0.69011	0.69011	0.98669	0.98669
1	0.20218	0.97092	0.25596	0.94608	0.013224	0.999911
2	0.026587	0.99751	0.047468	0.99354	8.8615×10^{-5}	0.9999996
3	2.3308×10^{-3}	0.99984	5.8687×10^{-3}	0.99941	3.9588×10^{-7}	1
4	1.5325×10^{-4}	0.999992	5.4417×10^{-4}	0.999957	1.32464×10^{-9}	1
5	8.0608×10^{-6}	1	4.0367×10^{-5}	0.9999974	3.5555×10^{-12}	1

a. Calculated from the mean Poisson value entered in the performance model.

further analysis. The rate of release of these materials was taken directly from data used for the waste package degradation modeling.

I.2.5 WASTE FORM DEGRADATION

The *waste form degradation model* evaluates the interrelationship among the in-package water chemistry, the degradation of the waste form (including cladding), and the mobilization of radionuclides (DIRS 153246-CRWMS M&O 2000, pp. 3-92 to 3-129 and DIRS 155950-BSC 2001, Sections 9.3.1-9.3.2, 10.3.1, and 10.3.4). The model consists of components that:

- Define the radioisotope inventories for representative commercial spent nuclear fuel and codisposal waste packages (this is the inventory abstraction discussed in more detail in Section I.3.1)

- Evaluate in-package water chemistry—in-package chemistry component abstraction (using chemistry lookup tables developed from detailed process model studies and calculations involving other model parameters)

- Evaluate the matrix degradation rates for commercial spent nuclear fuel, DOE-owned spent nuclear fuel, and high-level radioactive waste forms—waste form matrix degradation component abstractions (a temperature- and pH-dependent rate equation with several parameters, such as rate constants and activation energies, represented by statistical distributions)

- Evaluate the rate of Zircaloy cladding degradation (in the case of commercial spent nuclear fuel)—cladding degradation component abstraction with the following components:

  – Initial failure of Zircaloy cladding represented by a triangular distribution (low, mode, and high fraction of rods failed)

  – Creep failure of Zircaloy cladding represented by a series of triangular distributions, with a low value, mode value and high value, for fraction of rods perforated; each distribution for a specific peak waste package temperature range

  – Localized corrosion of Zircaloy cladding represented as a function of the water flux into the waste package, or a small, constant rate if there is no seepage

  – Assumption of total perforation of all stainless-steel cladding at time zero

  – Seismically induced cladding failure as all cladding would fail when a discrete event frequency of 0.0000011 per year occurred

  - A cumulative distribution of cladding unzipping rate coefficients; the coefficients are multiplied by the fuel matrix dissolution rate to obtain unzipping velocity

  - Effective exposure area of matrix (for radionuclide distribution) as a function of cladding perforation and unzipping

- Evaluate the radionuclide concentrations for aqueous phases—dissolved radionuclide concentration component abstraction (distributions of solubilities as a function of pH and temperature in the waste package; solubilities are also checked for possible limitations due to waste form degradation rate or package inventory)

- Evaluate diffusion of radionuclides in the waste package (DIRS 155950-BSC 2001, Section 10.3.1)

- Evaluate sorption of radionuclides in the waste package (DIRS 155950-BSC 2001, Section 10.3.4)

- Evaluate the waste form colloidal phases—colloidal radionuclide concentration component abstraction (reversible and irreversible colloid models)

I.2.6 ENGINEERED BARRIER TRANSPORT

The waste form would be the source of all radionuclides considered for the engineered barrier system. Radionuclides could be transported downward through the invert and into the unsaturated zone. Transport could occur by diffusion or by advection, depending on the route of the transport. The *engineered barrier system transport abstraction* (DIRS 153246-CRWMS M&O 2000, pp. 3-130 to 3-143) conservatively assumes that diffusion could occur once stress corrosion cracks form, regardless of whether conditions were appropriate for a continuous liquid pathway to exist. Colloid-facilitated transport of radionuclides was included as a transport mechanism. Radionuclides would be transported from the waste package either as dissolved species or bound in, or attached to, colloids.

The abstraction simulates the following transport modes:

- Waste package to invert path
  - Diffusion through stress corrosion cracks
  - Diffusion and advection through patches failed by bulk corrosion

- Invert to unsaturated zone path - Diffusion, sorption and advection through the invert (DIRS 155950-BSC 2001, Section 10.3.3 and 10.3.4)

Diffusion is represented by a diffusion transport equation with an empirical effective diffusivity that is a function of liquid saturation, porosity, and temperature. Sorption on corrosion products is characterized by a linear isotherm (K_D). Advective transport is represented by a liquid transport equation with the velocity determined by the engineered barrier system flow abstraction discussed above.

I.2.7 UNSATURATED ZONE TRANSPORT

Unsaturated zone transport refers to the movement of radionuclides from the engineered barrier system of the proposed repository, through the unsaturated zone, and to the water table. The unsaturated zone would be the first natural barrier to radionuclides that escaped from the potential repository. The unsaturated zone would act as a barrier by delaying radionuclide movement. If the delay was long enough for significant decay of a specific radionuclide, the unsaturated zone could have a significant effect on the ultimate dose from releases of that radionuclide to the environment. The *unsaturated zone transport model* (DIRS 153246-CRWMS M&O 2000, pp. 3-144 to 3-156, and DIRS 155950-BSC 2001, Section 11.3) is used to describe how radionuclides move through the unsaturated zone. The unsaturated zone model considers transport through welded tuff and nonwelded tuff and flow through both the fractures and the rock matrix. In addition, the model accounts for the existence of zeolitic alterations in some regions. These zeolitic tuffs are characterized with low permeability and enhanced radionuclide sorption.

The unsaturated zone water flow would provide the background on which the unsaturated zone transport took place. The model uses the flow fields developed using the unsaturated zone flow model, as described in Section I.2.2. Radionuclides can migrate in groundwater as dissolved molecular species or by being associated with colloids. Five basic processes affect the movement of dissolved or colloidal radionuclides:

- Advection (movement of dissolved and colloidal material with the bulk flow of water) including drift shadow effects on the seepage below the repository (DIRS 155950-BSC 2001, Section 11.3.1)
- Diffusion (movement of dissolved or colloidal material because of random motion at the molecular or colloidal particle scale)
- Sorption (a combination of chemical interactions between solid and liquid phases that reversibly partition radionuclides between the phases)
- Hydrodynamic dispersion (spreading of radionuclides perpendicular to and along the path of flow as they transport caused by localized variations in the flow field and by diffusion)
- Radioactive decay

Sorption is potentially important because it slows, or retards, the transport of radionuclides. Diffusion of radionuclides out of fractures into matrix pores is also a potential retardation mechanism because matrix transport is generally slower than fracture transport. However, sorption and matrix diffusion have less effect on colloids, so radionuclides bound to colloids can be more mobile than radionuclides dissolved in water. Radioactive decay could be important both from quantity reduction of certain radionuclides and the behavior of decay products that can have different transport properties than the decayed radionuclide.

The unsaturated zone transport model was implemented in the TSPA model as an embedded computer code that simulates the three-dimensional transport using a residence-time, transfer-function, particle-tracking technique. The key parameters such as sorption coefficients, diffusion coefficients, dispersivity, fracture spacing, and colloid parameters (partitioning, retardation, colloid size, fraction of colloids exchanging between matrix units) are all input as uncertainty distributions. The results are expressed as breakthrough curves (normalized fraction of total amount of radionuclide arriving at the saturated zone as a function of time) for each radionuclide. These are the inputs for saturated zone transport modeling.

I.2.8 SATURATED ZONE FLOW AND TRANSPORT

The saturated zone at Yucca Mountain is the region beneath the ground surface where rock pores and fractures are fully saturated with groundwater. The upper boundary of the saturated zone is called the water table. The proposed repository would be approximately 300 meters (1,000 feet) above the water table in the unsaturated zone.

As on the surface, underground water flows down the hydraulic gradient. Based on water-level observations in area wells, groundwater near Yucca Mountain flows generally in a north-to-south direction. The major purpose of the *saturated zone flow and transport model* (DIRS 153246-CRWMS M&O 2000, pp. 3-156 to 3-174, and DIRS 155950-BSC 2001, Sections 12.3.1 and 12.3.2) is to evaluate the migration of radionuclides from their introduction at the water table below the potential repository to the point of release to the biosphere (for example, a water supply well). Radionuclides can move through the saturated zone either as a dissolved solute or associated with colloids. The input to the saturated zone is the spatial and temporal distribution of mass flux of radionuclides from the unsaturated zone. The output of the saturated zone flow and transport model is a mass flux of radionuclides in the water used by a hypothetical farming community.

I.2.8.1 Saturated Zone Flow

The *saturated zone flow submodel* (DIRS 153246-CRWMS M&O 2000, pp. 3-157 to 3-164 and DIRS 155950-BSC 2001, Section 12.3.1) takes inputs from the unsaturated zone flow submodel and produces outputs, in the form of flow fields, for the saturated zone transport submodel. The saturated zone flow submodel incorporates a significant amount of geologic and hydrologic data taken from drill holes near Yucca Mountain. The saturated groundwater flow in the vicinity of Yucca Mountain can be estimated by knowing the porosity of the flow media, the hydraulic conductivity, and the recharge of water into the flow media. The primary tool used to describe saturated zone flow is a numerical model formulated in three dimensions. The three-dimensional saturated zone flow model has been developed specifically to determine the groundwater flow field at Yucca Mountain. The model was used to produce a library of flow fields (maps of groundwater fluxes). In addition, a GoldSim-based one-dimensional version of the model was used to provide flow information for a one-dimensional model of transport of radionuclide decay products.

I.2.8.2 Saturated Zone Transport

The *saturated zone transport submodel* (DIRS 153246-CRWMS M&O 2000, pp. 3-157 to 3-164, and DIRS 155950-BSC 2001, Section 12.3.2) takes inputs in the form of radionuclide mass fluxes from the unsaturated zone transport submodel and produces outputs in the form of radionuclide mass fluxes to the biosphere model. The saturated zone transport model incorporates a substantial amount of laboratory and field data taken from a variety of sources.

Radionuclides released from a repository at Yucca Mountain to the groundwater would enter the saturated zone beneath the repository and would be transported first southeast, then south, toward the Amargosa Desert. The radionuclides could be transported by the groundwater in two forms: as dissolved species or associated with colloids. Dissolved species typically consist of radionuclide ions complexed with various groundwater species, but still at molecular size. Colloids are particles of solids, typically clays, silica fragments, or organics, such as humic acids or bacteria, that are larger than molecular size, but small enough to remain suspended in groundwater for indefinite periods. Colloids are usually considered to have a size range of between a nanometer and a micrometer. A radionuclide associated with a colloid can transport either attached to the surface or bound within the structure of the colloid.

Transport through the saturated zone was primarily modeled using a three-dimensional particle-tracking method (DIRS 153246-CRWMS M&O 2000, pp. 3-168 to 3-169). The three-dimensional transport model was not used directly by the TSPA model. It was used to generate a library of breakthrough curves—distributions of transport times that are used, along with a time-varying source term from the unsaturated zone, to calculate the releases at the geosphere/biosphere boundary. The model accounts for the flow of groundwater and its interaction with varying media along the flow path. In the volcanic rocks that comprise the saturated media in the immediate vicinity of Yucca Mountain, groundwater flows primarily through fractures, while a large volume of water is held relatively immobile in the surrounding rock matrix. Radionuclides would travel with the moving fracture water but, if dissolved, could diffuse between the matrix water and fracture water. This transfer between fracture and matrix water is characteristic of a dual-porosity system. The saturated zone transport model is a dual-porosity model.

The media at greater distances from Yucca Mountain are alluvial gravels, sands and silts. The model simulates these areas as a more uniform porous material. While there is a possibility for channelized flow in the alluvium, current data indicate little evidence of dual-porosity behavior that would indicate this (DIRS 155950-BSC 2001, p. 12-23).

A one-dimensional saturated zone transport model was used to account for decay and ingrowth during transport. This model was incorporated directly in the GoldSim model as a series of pipes. The advantage of using the one-dimensional model is that the radionuclide masses can be accounted for directly. The disadvantage is that the flow and transport geometry is necessarily simplified.

I.2.9 BIOSPHERE

If the radionuclides were removed from the saturated zone in water pumped from wells, the radioactive material could result in dose to humans in several ways. For example, the well water could be used to irrigate crops that would be consumed by humans or livestock, to water stock animals that would be consumed by humans as dairy or meat products, or to provide drinking water for humans. In addition, if the water pumped from irrigation wells evaporated on the ground surface, the radionuclides could be left as fine particulate matter that could be picked up by the wind and inhaled by humans. The *biosphere pathway model* (DIRS 153246-CRWMS M&O 2000, pp. 3-175 to 3-187) was used to predict radiation exposure to a person living in the general vicinity of the repository if there was a release of radioactive material to the biosphere after closure of the proposed repository. The model uses a biosphere dose conversion factor that converts saturated zone radionuclide concentrations to annual individual radiation dose. The biosphere dose conversion factor was developed by analyzing the multiple pathways through the biosphere by which radionuclides can affect a person. The biosphere scenario assumed a *reference person* living in the Amargosa Valley region at various distances from the repository. People living in the Town of Amargosa Valley would be the group most likely to be affected by radioactive releases. An adult who lives year-round at this location, uses a well as the primary water source, and otherwise has habits (such as the consumption of local foods) similar to those of the inhabitants of the region. Because changes in human activities over millennia are unpredictable, the analysis assumed that the present-day reference person described future inhabitants. Strict definitions for the reference person (the Reasonably Maximally Exposed Individual, or RMEI) have been prescribed in 40 CFR Part 197. The chemically toxic materials were not evaluated in the biosphere model because there are no usable comparison values for radiologic and nonradiologic dose. Rather, a separate analysis of concentrations of these materials was made. The concentrations were then compared to available regulatory standards, such as the Maximum Contaminant Level Goal if available, or to the appropriate Oral Reference Dose.

The biosphere is the last component in the chain of TSPA model subsystem components. There are two connections between the biosphere submodel and other TSPA model submodels. One is for the groundwater irrigation scenario (nominal scenario), where the biosphere is coupled to the saturated zone flow and transport model; and the other is for the disruptive scenario, where the biosphere is coupled to the volcanic dispersal model. For the human intrusion scenario, the biosphere model is coupled with the saturated zone flow and transport model, and the event is treated as a perturbation to the nominal scenario. The groundwater path doses are based on specific paths of groundwater flow derived from regional data.

The primary result of the biosphere modeling is the construction of biosphere dose conversion factor distributions for the groundwater-release scenarios and the volcanic-ash-release scenario (DIRS 157307-BSC 2001, all). For the nominal scenario, well withdrawal of groundwater is the source of water for drinking, irrigation, and other uses. A farming community at the point of withdrawal would use the water at a rate based on surveys of current usage. The hypothetical farming community consists of between 15 and 25 farms supporting about 100 people. All radionuclides reaching this community in groundwater were assumed to be mixed in the volume of water that the community would use (this is the concept of full “capture” of the total plume of contamination). The water usage was input as a distribution of values based on current water usage data. The exposure pathways routes taken by radionuclides through the biosphere from the source to an individual are typical for a farming community in this environment. Farming activities usually involve more exposure pathways than other human activities in the Yucca Mountain region, including ingestion of contaminated water and locally produced food as well as inhalation and direct exposure from soil contamination intensified by the significant outdoor activity inherent in a farming lifestyle.

During periods of very wet climate, the Amargosa Desert is actually a lake and the irrigated farm scenario on which the biosphere model is based is not applicable. This is consistent with regulatory guidance that indicates no attempt should be made to project future human behavior and lifestyles (even if driven by climate change). The approach used is conservative because the use of groundwater for irrigation and domestic purposes has the effect of bringing up relatively concentrated solutions of contaminants. In a scenario where the Amargosa Desert is a lake (as it was 20,000 years ago), this large quantity of water would dilute the radionuclides to very low concentrations. Furthermore, the use of water would follow a greatly altered pattern. Consideration of all this leads to the conclusion that peak doses would be much lower than those projected in the current analysis.

I.2.10 VOLCANISM

Igneous activity (flow of volcanic material as in a volcanic eruption) has been identified as a disruptive event that has a potential to affect repository long-term performance. Yucca Mountain is in a region that has had repeated volcanic activity in the geologic past. Although the probability of recurrence at Yucca Mountain during the next 10,000 years is small, it is greater than 1 chance in 10,000 and is, therefore, retained as a scenario.

If igneous activity occurred at Yucca Mountain, possible effects on the repository could be grouped into three areas:

- Igneous activity that would not directly intersect the repository (can be shown to have no effect on dose from the repository)

- Volcanic eruptions in the repository that would result in waste material being entrained in the volcanic magma or pyroclastic material, bringing waste to the surface (resulting in atmospheric transport of volcanic ash contaminated with radionuclides and subsequent human exposure downwind)

- An igneous intrusion intersecting the repository (no eruption but damage to waste packages from exposure to the igneous material that would enhance release to the groundwater and, thus, enhance transport to the biosphere)

Based on studies of past activity in the region, probabilities for different types of igneous activity were estimated. Each type of event was described in detail based on observation of effects of past activities. These descriptions include geometry of intrusions, geometry of eruptions, physical and chemical properties of volcanic materials, eruption properties (velocity, power, duration, volume, and particle characteristics). Most of the parameters describing the igneous activity were entered in the modeling as probability distributions.

A collection of different modeling approaches was used to develop responses to the different types of activity described above (DIRS 153246-CRWMS M&O 2000, pp. 3-187 to 3-216 and DIRS 157307-BSC 2001, Enclosure 1).

I.2.11 HUMAN INTRUSION

Human intrusion was modeled based on a stylized scenario that is a conceptualization of the assumptions outlined in the Environmental Protection Agency standard (DIRS 157307-BSC 2001, Enclosure 1). The assumptions are based on recommendations of the National Research Council of the National Academy of Sciences. The Council observed that it is not possible to predict human behavior over the extremely long periods of concern and prescribed the scenario as a reasonable representation of typical inadvertent intrusion.

The models used were the same as those for the nominal scenario, except a source term was introduced for the time of the intrusion. This source term is characteristic of direct penetration of a waste package with a drill bit (DIRS 157307-BSC 2001, Enclosure 1).

I.2.12 NUCLEAR CRITICALITY

A nuclear criticality occurs when sufficient quantities of fissionable materials come together in a precise manner and the required conditions exist to start and sustain a nuclear chain reaction. One of the required conditions is the presence of a moderator, such as water, in the waste package. The waste packages would be designed to make the probability of a criticality occurring inside the waste package extremely small. In addition, based on an analysis of anticipated repository conditions, it is very unlikely that a sufficient quantity of fissionable materials could accumulate outside the waste packages in the precise configuration and with the required conditions to create a criticality. If, somehow, an external criticality was to occur, analyses indicate that it would have only minor effects on repository performance. In the unlikely event that a criticality occurred, there would be a short-duration localized rise in temperature and pressure, as well as an insignificant increase in the repository radionuclide inventory. No measurable effect on repository performance would result from this event (DIRS 153849-DOE 2001, p. 4-416).

I.2.13 ATMOSPHERIC RADIOLOGICAL CONSEQUENCES

In addition to the groundwater pathway, the analysis of long-term performance evaluated potential consequences of the release of radioactive gases into the environment. An analysis separate from the groundwater modeling described in the previous sections was used to forecast such consequences. The model used results from the waste package degradation models to evaluate when waste packages and fuel cladding would fail and, therefore, release contained radioactive gases. This model provided input to release and transport estimates for the atmospheric pathway. Section I.7 contains details of this analysis.

I.3 Inventory

This section discusses the inventories of waterborne radioactive materials used to model radiological impacts and of some nonradioactive, chemically toxic waterborne materials used in the repository environment that could present health hazards. This section also discusses the inventory of atmospheric radioactive materials.

I.3.1 INVENTORY FOR WATERBORNE RADIOACTIVE MATERIALS

There would be more than 200 radionuclides in the materials placed in the repository (see Appendix A of this EIS). In the Proposed Action, these radionuclides would be present in five basic waste forms: commercial spent nuclear fuel, mixed-oxide fuel and plutonium ceramic (called here *plutonium disposition waste*), borosilicate glass formed from liquid wastes on various DOE sites known as high-level radioactive waste, DOE-owned spent nuclear fuel, and naval spent nuclear fuel (DIRS 153246-CRWMS M&O 2000, Figure 3.5-4). In the repository, these wastes would be placed in several

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An abstracted inventory was used in the analysis of long-term groundwater impacts in much the same way as many other Features, Processes and Events were abstracted. The TSPA model is a high-level system model that performs hundreds of trials in a Monte Carlo framework. To make such a calculation tractable, it was necessary to reduce highly complex descriptions or behaviors to simplified concepts that capture the essential characteristics. In the case of inventory, the highly complex array of waste streams for the five fundamental waste categories (commercial spent nuclear fuel, plutonium-disposition waste, high-level radioactive waste, DOE-owned spent nuclear fuel, and naval spent nuclear fuel) were considered in developing the abstraction to representative waste packages that capture the essential features of the total inventory of radionuclide materials. The waste packages in the repository can be represented in two package types: a commercial spent nuclear fuel waste package and a codisposal waste package containing DOE spent nuclear fuel and high-level radioactive waste glass. The naval spent nuclear fuel was modeled as part of the commercial spent nuclear fuel. The plutonium disposition waste was split into the commercial spent nuclear fuel packages (mixed-oxide fuel) and codisposal package (immobilized plutonium within a high-level radioactive waste container) (DIRS 154841-BSC 2001, all).

The abstracted inventory has been carefully developed to maintain essential characteristics of the waste forms for the purpose of input to the TSPA model. As such, the TSPA abstracted inventory cannot be used for any other purpose, because it is not reality but rather a representation of reality that works only for the purpose intended. The averaging, blending, and screening of radionuclides to reduce the total number, while retaining essential physical characteristics of the waste, were all tailored to the TSPA model. Therefore, any attempt to compare this abstracted inventory with other abstractions used for other analyses in the repository will not be valid. The only essential comparison that can be made is that of the fundamental inputs to the abstraction process to fundamental inputs used in other analyses.

The abstraction of the inventory is shown in Figure I-2. In the figure, items in boxes are references to documents that either describe an analysis or are a data transmittal. The items not in boxes (next to the arrows) are the data produced from a documented analysis and used in another documented analysis.

Figure I-2 identifies four fundamental inputs:

- Input from DOE Environmental Management's National Spent Nuclear Fuel Program that identifies the characteristics of all DOE-owned spent nuclear fuel that would be sent to the repository (DIRS 110431-INEEL 1999, all)

- A body of high-level radioactive waste data collected from the EIS Data Call of 1997 (DIRS 104418-Rowland 1997); this includes information concerning high-level radioactive waste and plutonium-disposition waste

- A body of data that forms the database for commercial spent nuclear fuel; this is a collection of documents including key documents such as DOE/RW-0184 (DIRS 102588-DOE 1992, all) in its various revisions

- The *Monitored Geologic Repository Project Description Document* (DIRS 151853-CRWMS M&O 2000, all).

These four inputs were manipulated in various analyses that were brought together in the inventory abstraction (DIRS 157307-BSC, 2001, all) and are shown as the box at the bottom center of the figure. The fundamental data on commercial spent nuclear fuel was first processed in three analyses: simulation of a delivery schedule to the repository (DIRS 119348-CRWMS M&O 1999, all) (this was done using a standard computer code called CALVIN and source term studies for boiling-water reactor and pressurized-water reactor fuel that describe the typical radionuclide inventories for these spent fuels (DIRS 136428-CRWMS M&O 1999, all) (DIRS 136429-CRWMS M&O 1999, all). The CALVIN results are part of the input to the source term studies. All of the commercial spent nuclear fuel studies were then combined in a packaging study that describes the resulting spent nuclear fuel packages in the detailed design of the repository (DIRS 138239-CRWMS M&O 2000, all). The fundamental information on high-level radioactive waste was analyzed to determine decay and ingrowth of radionuclides in the waste and obtain inventory as a function of time (DIRS 147072-CRWMS M&O 1999, all). This study used the ORIGEN-S computer code, a standard code for determining inventories as a function of time. Fundamental data on DOE-owned spent nuclear fuel was analyzed to determine a packaging strategy (DIRS 149005-CRWMS M&O 2000, all). The results of this study identified three canister types and their inventories. At this point the results of commercial spent nuclear fuel, high-level radioactive waste, and DOE-owned spent nuclear fuel analyses were brought together in another analysis to develop a set of 13 standard package configurations (DIRS 153909-BSC 2001, all). This result was the basic set of detailed package configurations for the repository.

Another important analysis is the screening analysis. In this analysis, the contribution of specific radionuclides to inhalation and ingestion dose was determined and the radionuclides were ranked according to their contribution to total dose of all radionuclides (DIRS 153597-CRWMS M&O 2000, all). The metric for screening radionuclides is the radiation dose that a radionuclide could impose on a human living in the vicinity of Yucca Mountain. Identification of the important dose contributors is based on an estimate of the amount of radionuclides that could reach a human (DIRS 136383-CRWMS M&O 2000, all). Identification of the important dose contributors involves three steps:

1. For the waste form under consideration, the relative dose contribution from an individual radionuclide is calculated by multiplying its inventory abundance (in terms of its radioactivity) by its dose conversion factor (a number that converts an amount of a radionuclide into the dose that a human would incur if the radionuclide was ingested, inhaled, or came in close proximity). This multiplication gives a result that can be compared to values derived in the same manner for other radionuclides to determine the more important contributors to the dose.

2. The individual radionuclides are ranked, with the highest contributor to the dose given the highest ranking, and the percent contribution of each radionuclide in the list to the total dose (the sum of the doses from the radionuclides in the list) is calculated.

3. Radionuclides that are included in the analysis are the highest-ranked radionuclides that, when their dose contributions are combined, produce 95 percent of the dose.

These steps identify which radionuclides would be included in the dose estimate, if all the radionuclides in a waste form were released to the environment in proportion to their inventory abundance. However, radionuclides are not always released in proportion to their inventory abundance. Factors that can affect releases of radionuclides, depending on the scenario being considered, include radionuclide longevity, solubility, and transport affinity.

Radionuclide longevity is the lifetime of a radionuclide before it decays. Solubility is the amount of a radionuclide that will dissolve in a given amount of water. Transport affinity is a radionuclide's potential for movement through the environment. This movement can involve a number of mechanisms, for example: fracture flow (the movement of radionuclides with water flowing in fractures), matrix diffusion (the diffusion of radionuclides from water in the fractures into water in the matrix), or colloidal-facilitated transport (the movement of radionuclides associated with small particles of rock or waste form degradation products). Transport affinity is not a measurable property, but a qualitative description of the likelihood of transport. If a group of radionuclides is transported via a particular mechanism, and that mechanism dominates release, the group of radionuclides will be preferentially released (relative to radionuclides not in the group) to the environment. If a radionuclide has a short half-life, it will have a higher activity in the waste form at early times (close to repository closure); however, at later times, the radionuclide will have all but disappeared from the waste form. If a radionuclide is not soluble in the near-field environment around the waste package, it may not be released to the environment through groundwater transport, even if it is abundant and available.

Because radionuclide longevity, solubility, and transport affinity can affect releases of radionuclides, the identification of important dose contributors includes examination of possible "what-if" scenarios that could result in releases of radionuclides to the environment. For example, "What if radionuclide releases are the result of a colloidal transport mechanism? If the steps described above are applied to the subset of radionuclides that could be released through a colloidal-transport mechanism (radionuclides that readily bind to rock and colloidal particles), which of those radionuclides would be identified as the important contributors to dose?" Or, "What if a volcanic direct release to the environment occurs? If the steps described above are applied to the radionuclides present in the waste form in a direct release, which of those radionuclides would be identified as the important contributors to dose?" The radionuclide screening examined over 1,200 potential what-if scenarios and identified the important dose contributors for each one. The cases examined consider times from 100 to 1 million years after repository closure (100, 200, 300, 400, 500, 1,000, 2,000, 5,000, 10,000, 100,000, 300,000, and 1,000,000 years); eight waste forms (average and bounding pressurized-water reactor fuel, average and bounding boiling-water reactor fuel, average and bounding DOE spent nuclear fuel, and average and bounding DOE high-level radioactive waste); three transport affinity groups (highly sorbing, moderately sorbing, and slightly to nonsorbing); and two exposure pathways (inhalation and ingestion).

In addition to the radionuclides selected based on contribution to dose, other radionuclides (in particular radium-226 and radium-228) must be considered because of the groundwater protection requirements in 40 CFR Part 197. Other radionuclides must also be considered in the analysis because they belong to decay chains; they must be included to accurately track other members of the decay chains. (A decay chain is a sequence of radionuclides that, because of radioactive decay, change from one to the other; thus, the amount of one is dependent on the amounts of the others.)

The complete list of radionuclides produced by the screening merges all the lists of radionuclides developed from the various scenarios. For example, if a radionuclide is important for estimating the dose from DOE spent nuclear fuel, it is included in the analysis even though these waste forms would occupy a small fraction of the repository. Similarly, if a radionuclide is important for estimating the dose from the highly sorbing transport group, it is included in the analysis, even if analyses show that colloid transport is a minimal contributor to release.

The inventory abstraction then took as input the 13 configurations, the design of the repository, the screening analysis, and a special americium-241 ingrowth analysis (DIRS 153596-CRWMS M&O 2001, all). The abstraction provided two fundamental results:

- The total initial inventory for the TSPA model for the Proposed Action represented as the quantity of radionuclides in two representative waste package types. The total number of radionuclides represented has been reduced by a screening process with two criteria: elimination of all radionuclides with a half-life less than 20 years and inclusion of all radionuclides that contribute at least 95 percent of the total radiological dose.

- A recommended list of radionuclides to track for each of three scenarios: nominal scenario, disruptive events (volcanism) scenario, and human intrusion scenario. Not all radionuclides in the master list are necessarily included in a particular scenario. This is because some radionuclides are not important in some scenarios.

Additional analyses for this EIS included consideration of two other inventories that are not part of the Proposed Action. These analyses supported the analysis of cumulative impacts from possible future actions. The first of these is the addition of more commercial spent nuclear fuel. The combined inventory of the Proposed Action and this additional commercial spent nuclear fuel is referred to as Inventory Module 1. In addition, a category for Greater-Than-Class-C plus Special-Performance-Assessment-Required materials (Inventory Module 2 only) could be added in the future. The waste packages in this calculation include the commercial spent nuclear fuel packages and DOE spent nuclear fuel and high-level radioactive waste codisposal packages described in DIRS 150558-CRWMS M&O (2000, all). This EIS assumes that the Inventory Module 2 Greater-Than-Class-C and Special-Performance-Assessment-Required waste would be packaged in codisposal waste packages (DIRS 155393-CRWMS M&O 2000, Attachment II). The numbers of idealized waste packages used in the calculations are listed in Table I-4.

Table I-4. Modeled number of idealized waste packages by category type for the abstracted inventories of the Proposed Action, Inventory Module 1, and Inventory Module 2.

Waste category	Proposed Action	Inventory Module 1	Inventory Module 2
Commercial spent nuclear fuel[a]	7,860	11,754	0[b]
DOE spent nuclear fuel/high-level radioactive waste codisposal	3,910	4,877	0[b]
Greater-Than-Class-C	0	0	201
Special-Performance-Assessment-Required	0	0	400
Total	***11,770***	***16,631***	***601[b]***

a. 300 U.S. Navy spent nuclear fuel waste packages are modeled as commercial spent nuclear fuel waste packages.
b. Inventory Module 2 would include all packages in Inventory Module 1 plus the numbers shown for Greater-Than-Class-C and Special-Performance-Assessment Required waste packages; however, for modeling purposes only the *incremental increase* in the number of waste packages was modeled and the result added to the result for Inventory Module 1 impacts to estimate Inventory Module 2 impacts.

The physical properties of the various waste forms to be placed in the proposed Yucca Mountain repository are described in detail in DIRS 151109-CRWMS M&O (2000, all).

I.3.1.1 Radionuclide Inventory Used in the Model of Long-Term Performance for Proposed Action

The tabulated per-waste-package inventory used in the Proposed Action calculations is listed in Table I-5.

I.3.1.2 Radionuclide Inventory Used in the Model of Long-Term Performance for Inventory Module 1

The abstracted per-waste-package radionuclide inventory used for the Proposed Action also applies to additional waste packages for the expansion of the repository to include all potential commercial and DOE waste under Inventory Module 1. In other words, the number of packages is increased for Inventory Module 1 compared to the Proposed Action, but the content of each individual idealized waste package remains the same.

Table I-5. Abstracted inventory (grams) of radionuclides passing the screening analysis in each idealized waste package for commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste for Proposed Action, Inventory Module 1, and Inventory Module 2.[a,b]

Radionuclide	Commercial spent nuclear fuel waste packages	Codisposal waste packages: DOE spent nuclear fuel	Codisposal waste packages: High-level radioactive waste
Actinium-227	0.00000309	0.000113	0.000467
Americium-241	10,900	117	65.7
Americium-243	1,290	1.49	0.399
Carbon-14	1.37	0.0496	0.00643
Cesium-137	5,340	112	451
Iodine-129	1,800	25.1	48
Neptunium-237	4,740	47.9	72.3
Proactinium-231	0.00987	0.325	0.796
Lead-210	0	0.000000014	0.000000114
Plutonium-238	1,510	6.33	93.3
Plutonium-239	43,800	2,300	3,890
Plutonium-240	20,900	489	381
Plutonium-242	5,410	11.1	7.77
Radium-226	0	0.00000187	0.0000167
Radium-228	0	0.00000698	0.00000319
Strontium-90	2,240	55.4	288
Technetium-99	7,680	115	729
Thorium-229	0	0.0266	0.00408
Thorium-230	0.184	0.0106	0.00782
Thorium-232	0	14,900	7,310
Uranium-232	0.0101	0.147	0.000823
Uranium-233	0.07	214	11.1
Uranium-234	1,830	57.2	47.2
Uranium-235	62,800	8,310	1,700
Uranium-236	39,200	853	39.8
Uranium-238	7,920,000	509,000	261,000

a. Source: DIRS 154841-BSC (2001, Table 36, p. 38).
b. The idealized waste packages in the simulation (model) are based on the inventory abstraction. While the total inventory is represented by the material in the idealized waste packages, the actual number of waste packages emplaced in the potential repository would be different. The numbers of idealized waste packages modeled for various inventory abstractions are listed in Table I-4.

I.3.1.3 Radionuclide Inventory Used in the Model of Long-Term Performance for Inventory Module 2

Wastes with concentrations above Class-C limits (shown in 10 CFR 61.55, Tables 1 and 2) for long and short half-life radionuclides, respectively, are called Greater-Than-Class-C low-level waste. These wastes generally are not suitable for near-surface disposal. The Greater-Than-Class-C waste inventory is discussed in detail in Appendix A, Section A.2.5, of this EIS.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include production reactor operating wastes, production and research reactor decommissioning wastes, non-fuel-bearing components of naval reactors, sealed radioisotope sources that exceed Class-C limits for waste classification, DOE isotope production related wastes, and research reactor fuel assembly hardware. The Special-Performance-Assessment-Required waste inventory is discussed in detail in Appendix A.

The final disposition method for Greater-Than-Class-C and Special-Performance-Assessment-Required low-level radioactive waste is not known. If these wastes were to be placed in a repository, they would be placed in canisters before shipment. This appendix assumes the use of a canister similar to the naval dual-purpose canister described in Section A.2.2.5.6 of Appendix A of this EIS.

IDEALIZED WASTE PACKAGES

The number of waste packages used in the performance assessment simulations do not exactly match the number of waste packages projected for the Proposed Action.

The TSPA model uses two types of *idealized waste packages* (commercial spent nuclear fuel package and co-disposal package), representing the averaged inventory of all the actual waste packages used for a particular waste category.

While the number of idealized waste packages varies from the number of actual waste packages, the total radionuclide inventory represented by all of the idealized waste packages collectively is representative of the total inventory, for the radionuclides analyzed, given in Appendix A of this EIS for the purposes of analysis of long-term performance. The abstracted inventory is designed to be representative for purposes of analysis of long-term performance and cannot necessarily be used for any other analysis, nor can it be directly compared to any other abstracted inventory used for other analyses in this EIS.

Table I-6 lists existing and projected volumes through 2055 for the three Greater-Than-Class-C waste sources. DOE conservatively assumes 2055 because that year would include all Greater-Than-Class-C low-level waste resulting from the decontamination and decommissioning of commercial nuclear reactors. The projected volumes conservatively reflect the highest potential volume and activity expected based on inventories, surveys, and industry production rates.

The data concerning the volumes and projections of Greater-Than-Class-C low-level waste are from Appendix A-1 of the *Greater-Than-Class-C Low-Level Radioactive Waste Characterization: Estimated Volumes, Radionuclide Activities, and Other Characteristics* (DIRS 101798-DOE 1994, all). That appendix provides detailed radioactivity reports for such waste currently stored at nuclear utilities.

The only difference between Inventory Modules 1 and 2 is the addition of Greater-Than-Class-C and Special-Performance-Assessment-Required wastes under Inventory Module 2. This represents an incremental increase in the total inventory for Inventory Module 2 over Inventory Module 1, with no difference in the temperature operating mode or the areal extent of the repository disposal area. Because

Table I-6. Greater-Than-Class-C low-level waste volumes (cubic meters)[a] by source.[b]

Source	1993	2055
Nuclear electric utility	26	1,300
Sealed sources	39	240
Other	74	470
Totals	***139***	***2,010***

a. To convert cubic meters to cubic feet, multiply by 35.314.
b. Source: DIRS 101798-DOE (1994, Tables 6-1 and 6-3).

of this, calculations for analysis of long-term performance for Inventory Module 2 were performed considering only Greater-Than-Class-C and Special-Performance-Assessment-Required waste inventories, and the results treated as an incremental increase to the impacts predicted for analysis of long-term performance of Inventory Module 1.

The radionuclide inventory used for Inventory Module 2 (Greater-Than-Class-C and Special-Performance-Assessment-Required materials) is described and tabulated in Appendix A of this EIS and the abstracted per-package inventory developed from these data is listed on Table I-7. The details of

Table I-7. Abstracted inventory (grams) of radionuclides passing the screening analysis in each idealized waste package for Greater-Than-Class-C and Special-Performance-Assessment-Required waste (grams per waste package) under Inventory Module 2.[a,b]

Radionuclide	Greater-Than-Class-C and Special-Performance-Assessment-Required	Radionuclide	Greater-Than-Class-C and Special-Performance-Assessment-Required
Actinium-227	0	Plutonium-242	0.00614
Americium-241	40	Radium-226	0.0504
Americium-243	0.00151	Strontium-90	0.82
Carbon-14	28.9	Technetium-99	568
Cesium-137	771	Thorium-229	0
Iodine-129	0.000705	Thorium-230	0
Neptunium-237	0	Uranium-232	0.00000287
Protactinium-231	0	Uranium-233	0.00419
Lead-210	0	Uranium-234	0
Plutonium-238	1.56	Uranium-235	0
Plutonium-239	2,860	Uranium-236	0
Plutonium-240	0.0123	Uranium-238	563,000
Plutonium-241	0.0207		

a. Source: DIRS 157307-BSC (2001, Enclosure 1).
b. The idealized waste packages in the simulation (model) are based on the inventory abstraction. While the total inventory is represented by the material in the idealized waste packages, the actual number of waste packages emplaced in the potential repository would be different.

obtaining the per-package inventory for Greater-Than-Class-C and Special-Performance-Assessment-Required materials are described in DIRS 157307-BSC (2001, Attachment III).

I.3.2 INVENTORY FOR WATERBORNE CHEMICALLY TOXIC MATERIALS

Waterborne chemically toxic materials that present a potential human health risk would be present in materials disposed of in the repository. The most abundant of these materials would be nickel, chromium, and molybdenum (which would be used in the waste package) and uranium (in the disposed waste). Uranium is both a chemically toxic and a radiological material. Screening studies were conducted to determine if any of these or other materials would be released in sufficient quantities to have a meaningful impact on groundwater quality.

An inventory of chemical materials to be placed in the repository under the Proposed Action was prepared. The inventories of the chemical components in the repository were combined into four groups:

- Materials not part of engineered barrier system
- Components of the engineered barrier system including:
  - Titanium drip shields
  - Alloy-22 in the outer layer of the waste packages
  - Stainless steel in the inner layer of the waste packages
- Other materials internal to the waste packages
- High-level radioactive waste

These materials were organized into groups with similar release times for use in the screening study. Table I-8 lists the chemical inventories. Plutonium is not listed in Table I-8 because, while it is a heavy metal and therefore could have toxic effects, its radiological toxicity far exceeds its chemical toxicity (DIRS 102205-DOE 1998, Section 2.6.1). In addition, while there are radiological limits set for exposure

Table I-8. Inventory (kilograms)[a] of chemical materials placed in the Proposed Action repository.

	Inventory				
Element	Not part of engineered barrier system	Engineered barrier system components exposed before waste package failure	Internal to waste package including inner sleeve	High-level radioactive waste[b]	Totals
Aluminum	0	0	2,452,400	0	2,452,400
Barium	0	0	50,000	74,000[c]	124,000
Boron	0	0	197,400	0	197,400
Cadmium	0	0	3,400	43,000	46,400
Carbon	318,738	547	5,000	0	324,285
Chromium	0	23,735,000	26,414,000	0	50,149,000
Cobalt	0	0	27,000	0	27,000
Copper	243,800	0	3,000	0	246,800
Iron	111,916,880	1,190,000	161,695,000	0	274,801,880
Lead	0	0	0	2,000	2,000
Magnesium	0	0	12,000	0	12,000
Manganese	1,189,576	575,880	3,732,100	0	5,497,556
Mercury	0	0	0	200	200
Molybdenum	0	17,307,000	3,839,100	0	21,146,100
Nickel	0	60,797,000	18,659,100	0	79,456,100
Phosphorus	39,842	820	91,200	0	131,862
Selenium	0	0	0	300	300
Silicon	330,122	18,226	1,680,500	0	2,028,848
Sulfur	39,842	547	68,200	0	108,589
Titanium	0	4,148,000	2,000	0	4,150,000
Uranium	0	0	70,000,000	0	70,000,000
Vanadium	0	377,600	0	0	377,600
Zinc	0	0	3,000	0	3,000

a. To convert kilograms to pounds, multiply by 2.2046
b. The high-level radioactive waste form to be placed in the potential repository would not exhibit the Characteristic of Toxicity as measured by the Toxicity Characteristic Leaching Procedure (40 CFR 261.24).
c. Includes barium grown in from decay of all of the cesium.

to plutonium, no chemical toxicity benchmarks have been developed for this element. Therefore, lacking data to analyze chemical toxicity, plutonium was not analyzed for the chemical screening.

I.3.3 INVENTORY FOR ATMOSPHERIC RADIOACTIVE MATERIALS

The only radionuclide that would have a relatively large inventory and a potential for gas transport would be carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and therefore likely to dissolve in groundwater rather than migrate as a gas. Radon-222 is a gas, but would decay to a solid isotope before escaping from the repository region (see Section I.7.3). After carbon-14 escaped from the waste package, it could flow through the rock in the form of carbon dioxide. About 2 percent of the carbon-14 in commercial spent nuclear fuel occurs in a gas phase in the space (or *gap*) between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92). The gas-phase inventory consists of 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package. Table I-9 lists the carbon-14 inventory for commercial spent nuclear fuel under the Proposed Action and Inventory Modules 1 and 2.

I.4 Extension of TSPA Methods and Models for EIS Analysis of Long-Term Performance

The TSPA model nominal scenario is equivalent to the Proposed Action inventory for an individual at the RMEI location [approximately 18 kilometers (11 miles) downgradient from the proposed repository]. Details on the adaptations, extensions, and modifications to the software and models used for the TSPA

Table I-8. Inventory (kilograms)[a] of chemical materials placed in the Proposed Action repository.

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Aluminum	0	0	2,452,400	0	2,452,400
Barium	0	0	50,000	74,000[c]	124,000
Boron	0	0	197,400	0	197,400
Cadmium	0	0	3,400	43,000	46,400
Carbon	318,738	547	5,000	0	324,285
Chromium	0	23,735,000	26,414,000	0	50,149,000
Cobalt	0	0	27,000	0	27,000
Copper	243,800	0	3,000	0	246,800
Iron	111,916,880	1,190,000	161,695,000	0	274,801,880
Lead	0	0	0	2,000	2,000
Magnesium	0	0	12,000	0	12,000
Manganese	1,189,576	575,880	3,732,100	0	5,497,556
Mercury	0	0	0	200	200
Molybdenum	0	17,307,000	3,839,100	0	21,146,100
Nickel	0	60,797,000	18,659,100	0	79,456,100
Phosphorus	39,842	820	91,200	0	131,862
Selenium	0	0	0	300	300
Silicon	330,122	18,226	1,680,500	0	2,028,848
Sulfur	39,842	547	68,200	0	108,589
Titanium	0	4,148,000	2,000	0	4,150,000
Uranium	0	0	70,000,000	0	70,000,000
Vanadium	0	377,600	0	0	377,600
Zinc	0	0	3,000	0	3,000

a. To convert kilograms to pounds, multiply by 2.2046
b. The high-level radioactive waste form to be placed in the potential repository would not exhibit the Characteristic of Toxicity as measured by the Toxicity Characteristic Leaching Procedure (40 CFR 261.24).
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Table I-9. Carbon-14 gaseous inventory from commercial spent nuclear fuel (curies).[a]

Modeled inventory	Quantity[b]
Proposed Action	959
Module 1	1,434
Module 2	1,434

a. Impacts of carbon-14 in solid form are addressed as waterborne radioactive material impacts.

b. Based on 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package, based on 2 percent of the carbon-14 in commercial spent nuclear fuel existing as a gas in the gap between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92).

model necessary to analyze impacts under Inventory Modules 1 and 2 and at additional individual locations 30 and 60 kilometers (19 and 37 miles) downgradient from the repository are presented in this section.

I.4.1 METHODOLOGY

The calculations presented in this EIS were performed using the numerical code GoldSim, Version 7.17.200 (DIRS 155182-BSC 2001, all). The GoldSim calculations were performed for the conceptual/ process modeling of the proposed Yucca Mountain Repository described in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and expanded upon in the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, all; DIRS 154659-BSC 2001, all).

The performance assessment calculations for both the TSPA–Site Recommendation, the Supplemental Science and Performance Analyses, and the analysis of long-term performance calculations described in this EIS were performed within a probabilistic framework combining the most likely ranges of behavior for the various component models, processes, and corresponding parameters included in the overall conceptual/process model describing the performance of the repository.

The GoldSim software integrated the submodels using a Monte-Carlo simulation-based methodology to create multiple random combinations of the uncertain variables, and computed the probabilistic performance of the entire waste-disposal system in terms of annual individual dose. The GoldSim software calculated radionuclide release and radiological dose (the annual committed effective dose equivalent as defined in 40 CFR 197.2 from individual radionuclides and the total annual dose due to all radionuclides released from the repository from failed waste packages). In this EIS, the annual committed effective dose equivalent is referred to as the annual individual dose. GoldSim calculated the total annual dose for 300 realizations of the model configuration for the nominal scenario, and 5,000 realizations for the igneous activity scenario, using randomly selected values of distributed parameters for each realization. The calculation results are available in two main forms: (1) probability distributions for peak dose to an individual, and (2) time histories of annual dose to an individual.

The recently promulgated Environmental Protection Agency Final Rule 40 CFR Part 197 stipulates that the performance assessment of the proposed Yucca Mountain Repository include an estimate of dose to the reasonably maximally exposed individual. The Rule further states that this assessment provide, for 10,000 years, the reasonably maximally exposed individual annual committed effective dose equivalent (40 CFR 197.20 and 197.25). For the purposes of this EIS, the analysis of long-term performance must calculate the peak dose that would occur within the period of geologic stability (40 CFR 197.35). The peak dose is projected to occur within 1,000,000 years.

The methodology used for the calculations presented in this EIS draws upon the extensive analyses carried out in support of the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and in the *FY01 Supplemental Science and Performance Analyses*, Volumes 1 and 2 (DIRS 155950-BSC 2001, all, and DIRS 154659-BSC 2001, all). Only those model components and related parameters that were modified to account for the scenarios considered in addition to those used in the TSPA–Site Recommendation or the *FY01 Supplemental Science and Performance Analyses* are described in this EIS. In addition, the model configuration used for the calculations presented in this EIS was modified to conform to the recently promulgated U.S. Environmental Protection Agency Final Rule. The Final Rule provides the criteria to be used in determining the RMEI location [40 CFR 197.21(a)], the other criteria of the RMEI (that were applied in the calculation of biosphere dose-conversion factors), and the groundwater protection standard, including the representative volume to be used for the calculation of gross alpha activity, total radium activity, and whole-body dose (40 CFR 197.30, Table 1). These modifications are described in Section I.4.4.

This EIS considers inventories in addition to those described in the TSPA–Site Recommendation and the *Supplemental Science Performance Analyses* for the 70,000 MTHM inventory. The calculations in this EIS include the Proposed Action (70,000 MTHM inventory) under both the higher-temperature repository operating mode and lower-temperature operating mode, and the Module 1 and 2 inventories under the higher-temperature operating mode, for the following scenarios:

- The nominal scenario that considers performance of the repository under undisturbed conditions, but including seismic activity.

- The human intrusion scenario (DIRS 153246-CRWMS M&O 2000, Section 4.4, pp. 4-25 to 4-32), that considers an "intruder" drilling a land-surface borehole using a drilling apparatus (under the common techniques and practices currently employed in exploratory drilling for groundwater in the region around Yucca Mountain), drilling directly through an intact or degraded waste package, and subsequently into the uppermost aquifer underlying Yucca Mountain. The intrusion then causes the subsequent compromise and release of contaminated material in the waste package. The human-intrusion scenario was simulated for a 1-million year performance period with the intrusion at 30,000 years after repository closure.

- The igneous activity scenario contains two separate possible events: a volcanic eruption that includes exposure as a result of atmospheric transport and deposition on the ground, and an igneous intrusion groundwater transport event (DIRS 155950-BSC 2001, Section 14.2.1, p. 14-5). In the volcanic eruption event (DIRS 153246-CRWMS M&O 2000, Section 3.10, pp. 3-187 to 3-216), a dike (or dikes) would intersect the repository and compromise all waste packages in the conduit. Then, an eruptive conduit of an associated volcano would intersect waste packages in its path. Waste packages in the path of the conduit would be sufficiently damaged that they provide no further protection, and the waste in the packages would be entrained in the eruption and subject to atmospheric transport. In the igneous intrusion groundwater transport event, the analysis calculated releases caused by a dike (or dikes) intersecting emplacement drifts, causing varying degrees of waste-package damage.

I.4.2 ASSUMPTIONS

This section identifies assumptions that are essential for this calculation. The assumptions listed here contribute to the generation of results reported in Sections I.5 and I.6 of this appendix.

1. The Proposed Action (70,000-MTHM) model configuration for the calculations in this EIS consists of the *FY01 Supplemental Science and Performance Analyses* model (DIRS 155950-BSC 2001, all), which differs from the TSPA–Site Recommendation model (DIRS 153246-CRWMS M&O 2000, all).

The model used for the calculations in Sections I.5 below includes the modifications from the Supplemental Science and Performance Analyses and TSPA–Site Recommendation models as described below in Section I.4.4. Other assumptions incorporated into the Supplemental Science and Performance Analyses model are documented in the *FY01 Supplemental Science and Performance Analyses* Volume 2 (DIRS 154659-BSC 2001, Section 2, all). The key differences between the Supplemental Science and Performance Analyses and the model configuration used in the calculations presented in this EIS are described in Section I.4.4.

2. The radionuclide inventories used in the calculations in Section I.5 are those developed in the *Inventory Abstraction* Analysis Model Report (DIRS 154841-BSC 2001, Table 36, p. 38). The per-waste-package inventories for commercial spent nuclear fuel and codisposal waste packages are the same as those used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.5.1, pp. 3-94 to 3-100), but the DOE-owned spent nuclear fuel inventory does not include naval spent nuclear fuel. The naval spent nuclear fuel is conservatively represented by commercial spent nuclear fuel (DIRS 152059-BSC 2001, all, and DIRS 153849-DOE 2001, Section 4.2.6.3.9, p. 4-257). The per-waste-package inventories used for the Greater-Than-Class-C calculations use the Greater-Than-Class-C inventory presented in Attachment VI of the *EIS Performance–Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, p. VI-5) divided according to the number of packages indicated in DIRS 155393-CRWMS M&O (2000, Attachment VI).

I.4.3 USE OF COMPUTER SOFTWARE AND MODELS

The calculations described in this EIS were performed using the numerical code GoldSim, Version 7.17.200 (DIRS 155182-BSC 2001, all). GoldSim was developed by Golder Associates as an update to the baseline software RIP v.5.19.01 (DIRS 151395-Golder Associates 1998, all). GoldSim is an object-oriented program that is computationally similar to RIP v.5.19.01, which was used for the TSPA–Viability Assessment (DIRS 101779-DOE 1998, Volume 3, p. 2-29). GoldSim is designed such that probabilistic simulations can be conducted and represented graphically.

I.4.4 MODIFICATIONS TO THE TSPA–SITE RECOMMENDATION AND SUPPLEMENTAL SCIENCE AND PERFORMANCE ANALYSIS MODELS

This EIS builds on the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all) and *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, all) modeling of the Proposed Action (70,000-MTHM) repository configuration. Because this EIS evaluates the possible consequences of ultimately including the entire commercial spent nuclear fuel, DOE-owned spent nuclear fuel, and high-level radioactive waste inventories, an expanded repository area was also considered.

The change from the TSPA–Site Recommendation waste inventory and repository area to a calculation of the performance of an expanded repository includes addition of the Lower Block, shown on Figure I-3, in the calculations. The TSPA–Site Recommendation and Supplemental Science and Performance Analyses reports relied only on a detailed analysis of just the Primary Block shown on Figure I-3.

The GoldSim numerical code simulates transport of radionuclides from the repository, through the unsaturated zone, and through the saturated zone to the accessible environment. The different process models included in the GoldSim code are fully described and documented in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, all). The unsaturated zone transport release nodes and saturated zone transport capture areas for the 70,000-MTHM inventory in the TSPA–Site Recommendation and Supplemental Science and Performance Assessment models were modified for Inventory Modules 1 and 2 to include the Lower Block emplacement area (DIRS 157307-BSC 2001, all).

The GoldSim model configuration used for the Supplemental Science and Performance Analyses was modified to conform to the recently published Environmental Protection Agency Final Rule 40 CFR Part 197. The model also assesses the performance of additional radionuclide inventories and performance scenarios. Sections I.4.4.1 through I.4.4.8 describe the modifications to the TSPA–Site Recommendation and Supplemental Science and Performance Analyses models. The model configuration for the calculations in this EIS differs from earlier performance assessment models in the following areas:

- The model used for the calculations in this EIS used biosphere dose conversion factor based on the RMEI defined in 40 CFR 197.21. The models used in the TSPA–Site Recommendation and Supplemental Science and Performance Analyses used different biosphere dose conversion factors based on the average member of the critical group in the then-proposed 10 CFR 63.115.

- The length of the saturated zone simulated in the model configuration for the calculations in this EIS extends from inside the repository footprint to latitude 36 degrees 40 minutes 13.6661 seconds north, above the highest concentration of radionuclides in the plume of contamination. The RMEI is assumed to reside at this location in the accessible environment. The latitude at this location is at the southwestern corner of the Nevada Test Site.

- Groundwater protection was assessed using an annual representative volume of 3.7 million cubic feet (exactly 3,000 acre-feet) per year of groundwater, as specified at 40 CFR Part 197, to calculate the total alpha activity, the total radium concentration, and the whole-body dose. To calculate all other concentrations not included in the groundwater-protection standard, the water usage was assigned in the same probabilistic manner used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.9.2.4, p. 3-184) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 13.3.5, pp. 13-41 to 13-44).

- The waste inventories used for the calculations in this EIS are presented in DIRS 154841-BSC (2001, Table 36, p. 38).

- Waste-package corrosion for the calculations in this EIS would be due to general corrosion independent of temperature, as was true for the TSPA–Site Recommendation. The Supplemental Science and Performance Analyses calculations included temperature-dependent waste package corrosion.

- The process-level lower-temperature operating mode thermal-hydrologic results for this EIS were corrected from those presented in the Supplemental Science and Performance Analyses to include radiative heat transfer in the unsaturated zone modeling with the Nonisothermal Unsaturated-Saturated Flow and Transport model.

I.4.4.1 Modifications to FEHM Particle Tracker Input and Output

The unsaturated zone flow-and-transport modeling in the TSPA–Site Recommendation, in the *FY01 Supplemental Science and Performance Analyses*, and in this EIS are conducted with the Finite Element Heat and Mass (FEHM) model. The movement of fluid and radionuclides released from the waste packages was modeled in the unsaturated zone by means of a particle-tracking algorithm in the TSPA–Site Recommendation and Supplemental Science and Performance Analyses process models (DIRS 153246-CRWMS M&O 2000, p. 2-27; DIRS 155950-BSC 2001, Section 11). The particle-tracking files used in the TSPA–Site Recommendation were modified for the increased inventories of Modules 1 and 2 to allow the FEHM unsaturated zone input regions to correspond to the Lower Block area used for the simulations. The interface file in GoldSim was modified for this case by changing the FEHM nodes used for transport from the Primary Block as considered in the TSPA–Site Recommendation and the Supplemental Science and Performance Analyses for the Proposed Action inventory. The calculations presented in this EIS also include the Lower Block of a potential repository that would also be used for input of mass from an expanded repository area. The FEHM nodes were chosen to correspond to the Lower Block repository coordinates because of the changes to the regions from where mass is captured coming out of the FEHM model (DIRS 155393-CRWMS M&O 2000, Attachments II and III). Capture regions at the surface of the saturated zone would accumulate water and mass released from the repository that had been transported through the unsaturated zone. The capture regions for the Primary Block are shown in Figure I-4. These capture regions were modified to ensure all the mass would be captured and to distribute the mass to the saturated zone capture regions, including release from the Lower Block. Figure I-5 shows the capture regions used for Inventory Modules 1 and 2.

The repository nodes were extracted based on the information and representation of the repository configuration described in *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, Attachment II). The drifts in the Lower Block were first aggregated into larger groups based on similar elevations. Then the boundary coordinates of the larger groups were used to define rectangular regions. The Software Routine *repocoord1.f* (Version 1.0) (DIRS 155393-CRWMS M&O 2000, Attachment II) was used to extract FEHM nodes within the rectangular region. The extracted nodes were then plotted using SigmaPlot (Version 4.01, a commercial graphics software package) and nodes that fell beyond the defined drift region were removed from the repository node list. The use of *repocoord1.f* (Version 1.0) in these EIS calculations is documented in DIRS 155393-CRWMS M&O (2000, Attachment II).

I.4.4.2 Estimation of the Thermal Profiles and Infiltration for the Lower Block

The TSPA–Site Recommendation and *FY01 Supplemental Science and Performance Analyses* models used to assess repository performance utilized thermal-hydrologic modeling to estimate infiltration from land surface to the repository horizon. Infiltration water would be the principal cause of waste-package corrosion and the main agent for waste transport. The TSPA–Site Recommendation and *FY01 Supplemental Science and Performance Analyses* model conceptualizations for the Yucca Mountain Repository would be considered waste forms in discrete areal regions of the repository as source terms for flow and transport from the repository to the saturated zone. The GoldSim conceptualization for the TSPA–Site Recommendation considered the repository block, referred to as the Primary Block, to be comprised of four source regions (Figure I-4). The four regions are covered by the Yucca Mountain multiscale thermohydrologic model and its abstraction, which was used to develop the thermodynamic-environment time histories at different potential waste-package locations distributed throughout the Primary Block (DIRS 139610-CRWMS M&O 2000, Section 6.6, all; DIRS 154594-CRWMS M&O 2001, Section 6.3). These time histories for the higher-temperature operating mode were used in both the TSPA–Site Recommendation and the *FY01 Supplemental Science and Performance Analyses*.

The calculations for Inventory Modules 1 and 2 for this EIS used two additional areas for disposal, using an additional approximately 0.88 square kilometer (218 acres) of the Primary Block that was not used in the design of the Primary Block for the Proposed Action, the higher-temperature operating mode (DIRS 150941-CRWMS M&O 2000, Figure 4-14), and approximately 1.7 square kilometers (408 acres) of the Lower Block, which would be to the east of the Primary Block (Figure I-3). For Inventory Modules 1 and 2, source region 2 was expanded to the east so that its areal extent would include the Lower Block (Figure I-5) (DIRS 155393-CRWMS M&O 2000, Section 5.2.2, p. 11-12).

The following methodology was used to develop thermal histories for waste packages emplaced in the Lower Block. The thermal response from the multiscale thermohydrologic model (DIRS

149862-CRWMS M&O 2000, all) is correlated to the distance from the edge of the repository. Further, seepage into the drift would be a function of the local infiltration flux. Therefore, the location and estimated infiltration flux were used to select analogous Primary Block thermal-hydrologic responses for application to comparable locations in the Lower Block. Thus, the Primary Block thermal-hydrologic data were extended to the 51 Lower Block elements shown on Figure I-6. It should be noted that DOE would pursue a comprehensive characterization of these blocks before it used them for waste emplacement. The modeling work described in this EIS related to these uncharacterized blocks is limited to estimating the environmental impacts under the expanded inventory (Modules 1 and 2) configuration. The detail on extending this method to the 51 nodes is in DIRS 155393-CRWMS M&O (2000, Attachment II, pp. II-2 to II-5), and the estimation of lower-block infiltration seepage rates is in DIRS 155393-CRWMS M&O (2000, Attachment III, pp. III-2 to III-19). The glacial-transition climate infiltration rate for the 51 elements was estimated from the site-scale hydrologic model (DIRS 100103-Bodvarsson, Bandurraga, and Wu 1997, all). For each of the 51 Lower Block elements, the GoldSim code was configured with thermal history data sets from the site multiscale thermohydrologic model (DIRS 139610-CRWMS M&O 2000, Section 6.6, all, and its abstractions; DIRS 154594-CRWMS M&O 2001, Section 6.3) based on similar infiltration and proximity to the edge of the repository as the analogous Primary Block locations. Using these data, the infiltration categories, or bins, for the waste packages associated with the Inventory Modules 1 and 2 cases were established as described in Attachment IV of the calculation document *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, pp. IV-2 to IV-4). The use of thermal profiles in estimating infiltration to the repository blocks is described in detail in Attachment III of the calculation document *EIS Performance-Assessment Analyses for Disposal of Commercial and DOE Waste Inventories at Yucca Mountain* (DIRS 155393-CRWMS M&O 2000, pp. III-2 to III-19). DIRS 157307-BSC (2001, Attachment II) describes the calculation of the fractional Lower Block repository areas corresponding to the infiltration bins for these calculations.

I.4.4.3 Saturated Zone Breakthrough Curves

Transport in the saturated zone beneath the repository would be the main route for groundwater transport of contaminants leached from the repository. The radioactive contaminants would move through the saturated zone to the accessible environment. The accessible environment is defined as any area outside the controlled area (40 CFR 197.12). The Environmental Protection Agency Final Rule (40 CFR 197.12) specifies the following elements of the controlled area:

1. The surface area, identified by passive institutional controls, that encompasses no more than 300 square kilometers (about 74 acres). It must not extend farther:

   a. South than 36 degrees 40 minutes 13.6661 seconds north latitude, in the predominant direction of groundwater flow; and

   b. Than 5 kilometers (3 miles) from the repository footprint in any other direction; and

2. The subsurface underlying the surface area.

The location where the RMEI would reside, where groundwater protection was analyzed, would be the point above the highest concentration of radionuclides in the simulated plume of saturated zone contamination where the plume crossed the southernmost boundary of the controlled area (at a latitude of 36 degrees 40 minutes 13.6661 seconds North) and reached the accessible environment. For this analysis, DOE selected the southern boundary of the controlled area and the location of the RMEI to be at the limit discussed above, which is approximately 18 kilometers (11 miles) from the potential repository, compared to the corresponding distance of approximately 20 kilometers (12 miles) used in the saturated zone transport modeling for TSPA–Site Recommendation and the *FY01 Supplemental Science and*

Performance Analyses, as shown in Figure I-7. To analyze long-term performance with respect to the standard set in the Environmental Protection Agency Final Rule 40 CFR 197.12, additional saturated zone breakthrough curves, which describe the time-related arrivals of radionuclides at the RMEI location, were calculated for all radionuclides used in the calculations in this EIS. The saturated zone breakthrough curves were used in the analyses to simulate radionuclide transport from the water table beneath the proposed repository to the receptor location. Depending on the subsurface layout of a repository, the distance to the RMEI location from any point in the subsurface layout could be more or less than 18 kilometers. For convenience and consistency with other documents, the RMEI location is consistently discussed as being approximately 18 kilometers (11 miles) downgradient from the proposed repository.

To generate the saturated zone breakthrough curves used in the calculations in this EIS, 100 realizations of the saturated zone site-scale flow-and-transport model were performed as described for the saturated zone process model (DIRS 139440-CRWMS M&O 2000, Sections 6.2 and 6.3) to generate saturated zone breakthrough curves at the RMEI location. Other stochastic parameters for the saturated zone simulations use the same values as those used in the saturated zone breakthrough curves for the *FY01 Supplemental Science and Performance Analyses* (DIRS 154659-BSC 2001, Section 3.2.10). The simulated radionuclide breakthrough curves at the RMEI location exhibited shorter transport times than those at 20 kilometers (12 miles), as presented in *Supplemental Sciences and Performance Analyses* (DIRS 155950-BSC 2001, Section 13.2.1.3) on a realization-by-realization basis. In particular, radionuclides that could have significantly greater sorption in the alluvium than in the volcanic units (such as neptunium-237) exhibited shorter transport times to the RMEI location in this analysis relative to the 20-kilometer location used in the TSPA–Site Recommendation, the *Supplemental Science Performance Analyses*, and in the Draft EIS. This result is related to the fact that the RMEI location in this analysis would result in a decrease in the length of transport through the alluvium relative to the transport path to the 20-kilometer location.

The approach used for simulations of groundwater flow and radionuclide transport in the saturated zone used in this EIS is the same as the approach used in the TSPA–Site Recommendation. The saturated zone site-scale flow-and-transport model was used to simulate the unit radionuclide mass breakthrough curves for radionuclides of concern to the Site Recommendation at the RMEI location. In the model configuration for the calculations for this EIS, these saturated zone breakthrough curves are coupled with the other components of the system (mass flux and representative volume or water usage) using the convolution-integral method in the same manner as described and implemented in the GoldSim program for the TSPA–Site Recommendation and the *FY01 Supplemental Science and Performance Analyses* (DIRS 153246-CRWMS M&O 2000, Section 2.2.2; DIRS 155950-BSC 2001, Section 3.2.10). In addition, the simulation of radionuclide decay chains and the transport of decay products in the saturated zone system was performed using a one-dimensional model directly in the GoldSim numerical code.

In the saturated zone model, the capture regions that would accumulate flow and mass at the base of the unsaturated zone become the source regions for the saturated zone model. The four radionuclide source regions in the saturated zone (Figures I-4 and I-5) that were defined for the 70,000-MTHM case of the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.8.2.2 and Figure 3.8-14, p. F3-117) were used in the calculations in this EIS. For Inventory Modules 1 and 2, radionuclide mass originating from the Lower Block of the repository is applied to source region number 2 in the saturated zone transport module. The Lower Block of the expanded repository would extend farther to the east than the saturated zone source region number 2 for the TSPA–Site Recommendation base case. However, applying the radionuclide mass from the Lower Block to this source region constitutes a conservative approximation of transport in the saturated zone. Lower permeability rocks of the upper volcanic confining unit exist at the water table in the area immediately to the east of saturated zone source region number 2, which would result in slower initial advective groundwater velocity for radionuclide transport in this area. Preliminary results of radionuclide transport simulations with the saturated zone site-scale flow and transport model confirm that radionuclide transport times in the saturated zone from the area below the Lower Block would be longer than the transport times from saturated zone source region number 2 in the Proposed Action considered in this EIS.

I.4.4.4 Modification to the Waste Package Degradation Model

The WAste Package DEGradation (WAPDEG) model (DIRS 151566-CRWMS M&O 2000, all) was used to calculate drip shield and waste package degradation profiles with time in the GoldSim TSPA model configurations used for TSPA–Site Recommendation, *FY01 Supplemental Science and Performance Analyses*, and this EIS. Several input parameters to the WAPDEG model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, all) were reevaluated in the *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 7). The reevaluation led to the following changes to the TSPA–Site Recommendation WAPDEG model and parameters used in the *FY01 Supplemental Science and Performance Analyses* and the calculations in this EIS. These changes are described in detail in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 7) and are summarized here:

- All surface-breaking weld flaws and all weld flaws embedded in the outer one quarter of the closure weld thickness were considered capable of propagation in the radial direction in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 5.5, p. 39). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the fraction of these weld flaws capable of propagation in the radial direction is given by a ±3 standard deviation truncated lognormal distribution with a mean of 0.01 and bounded between 0.5 (+3 standard deviations) and 0.0002 (-3 standard deviations) (DIRS 155950-BSC 2001, Section 7.3.3.3.4, p. 7-41).

- The stress threshold for the initiation of stress corrosion cracking was given by a uniform distribution between 20 and 30 percent of the Alloy-22 yield strength in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 4.1.9, p. 29). In the *FY01 Supplemental Science and Performance Analyses* and for this analysis, the stress threshold for the initiation of stress corrosion cracking is given by a uniform distribution between 80 and 90 percent of the Alloy 22 yield strength (DIRS 155950-BSC 2001, Section 7.3.3.3.3, p. 7-39).

- The uncertainty bounds of the residual stress profile in the Alloy-22 waste package outer closure lid weld regions (induction annealed) were set to ±30 percent of the yield strength of Alloy-22 in the WAPDEG Model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.5.1, p. 79). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the uncertainty bounds of the residual stress profile in the Alloy-22 waste package outer closure lid weld regions were set to ±21.4 percent of the yield strength (DIRS 155950-BSC 2001, Section 7.3.3.3.1, p. 7-74).

- The uncertainty bounds of the residual stress profile in the Alloy-22 waste package inner closure lid weld regions (laser peened) were set to ±30 percent of the yield strength of Alloy-22 in the WAPDEG model developed for TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.5.1, p. 79). In the *FY01 Supplemental Science and Performance Analyses* and in this analysis, the uncertainty bounds of the residual stress profile in the Alloy-22 waste package inner closure lid weld regions were sampled from a cumulative distribution function (DIRS 155950-BSC 2001, Section 7.3.3.3.2, p. 7-37 and Table 7.3.3-2, p. 7T-4).

- The variances of the general corrosion rate distributions for Alloy-22 and titanium Grade 7 were considered to result from contributions of both uncertainty and variability in the WAPDEG model developed for the TSPA–Site Recommendation (DIRS 151566-CRWMS M&O 2000, Section 6.3.1, p. 55). In *FY01 Supplemental Science and Performance Analyses* and in this analysis, the total variance of the general corrosion rate distributions was treated as uncertainty (DIRS 155950-BSC

2001, Section 7.3.5.2, p. 7-54). To ensure conservatism in the analysis, the temperature-dependent Alloy-22 general corrosion model developed for the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 7.3.5.3.2, p. 7-56) was not used in this analysis. This is conservative because the non-temperature-dependent model uses a high bounding rate characteristic of high temperature, while the temperature-dependent model would take credit for long periods of lower temperatures and corresponding low corrosion rates. The same Alloy-22 and titanium Grade 7 general corrosion rate distributions used in the WAPDEG model developed for TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000. Section 3.4.1, pp. 3-80 to 3-87) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 7.3.5, pp. 7-52 to 7-61) were also used in the calculations in this EIS. The calculated means of the general corrosion rate distribution used for the calculations in this EIS are 1.94×10^{-4} millimeter (7.64×10^{-6} inch) per year for titanium Grade 7 and 6.80×10^{-5} millimeter (2.68×10^{-6} inch) per year for Alloy-22. The data used to calculate the means are from complementary distribution functions in *WAPDEG Analysis of Waste Package and Drip Shield Degradation* (DIRS 151566-CRWMS M&O 2000, Section 4, pp. 19 and 20).

I.4.4.5 Early Waste Package Failure

The potential waste package early failure mechanisms were reevaluated in the *FY01 Supplemental Science and Performance Analyses*, particularly improper heat treatment of waste packages (DIRS 155950-BSC 2001, Section 7.3.6, p. 7-62). These results are incorporated in the calculations in this EIS. The probability of having one or more waste packages in the repository improperly heat-treated is provided in Table I-3.

In evaluating the potential consequences of early failures by improper heat treatment for the *FY01 Supplemental Science and Performance Analyses* and this EIS, early waste-package failure would occur on initiation of corrosive processes and would be due to failure of the outer and inner closure lids of the waste package outer barrier and the failure of the closure lid of the stainless-steel structural waste package inner shell. Details of the use of this model in performance assessment analyses are discussed in *FY01 Supplemental Science and Performance Analyses*, Volume 2 (DIRS 154659-BSC 2001, Section 3.2.5.4, p. 3-21). The following elements were employed in that evaluation:

1. Those waste packages affected by early waste-package failure would fail immediately by general corrosion as patches (DIRS 154659-BSC 2001, Section 3.2.5.4, p. 3-21).

2. The area on the waste package affected by improper heat treatment would be equal to the area of closure-weld patches because improper heat treatment would be most likely to occur during the induction annealing of the outer closure lid welds of the waste-package outer barrier.

3. The materials of the entire affected area would be lost on failure of the waste packages because the affected area would be subject to stress-corrosion cracking and highly enhanced localized and general corrosion.

4. The weld region of the inner closure lid of the outer barrier and the closure lid of the stainless-steel structural inner shell would fail at the same time the outer closure-lid weld region failed.

These assumptions are conservative because only the weld region of the outer lid of the outer barrier would be affected by potential improper heat treatment during the stress mitigation heat treatment (induction annealing), and the inner lid of the outer barrier would be unlikely to be affected. In a more realistic scenario, the breached weld patches of the affected waste package would remain with the waste package until the weakened areas were affected by a major mechanical impact or corroded away by general corrosion.

I.4.4.6 Biosphere Dose Conversion Factors for the 40 CFR 197 Reasonably Maximally Exposed Individual

Biosphere dose conversion factors were used to estimate the radiation dose that would be incurred by an individual when a unit activity concentration of a radionuclide reached the accessible environment. The biosphere dose conversion factors for the RMEI were developed using the environmental and agricultural parameters characteristic of the Amargosa Valley region, and the dietary and lifestyle characteristics of the RMEI consistent with those specified in 40 CFR 197.21. The lifestyle characteristics of the RMEI were representative of a rural-residential population. The dietary characteristics of the RMEI were based on a food consumption survey (DIRS 100332-DOE 1997, all) for the population of the town of Amargosa Valley, Nevada. Consistent with the final rule at 40 CFR 197.21, the dietary characteristics of the RMEI were represented by the mean values of locally produced food for Amargosa Valley residents. The dietary and lifestyle attributes of the RMEI are listed in Table I-10. The dietary attributes were developed using the set of recently reevaluated and updated values of consumption rates of locally produced food in *Calculation: Consumption Rates of Locally Produced Food in Nye and Lincoln Counties* (DIRS 156016-BSC 2001, all). This set of consumption rates is different from the set used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.9) and the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Section 13) analyses. The changes include the update of the contingent average daily intakes of food, adjustments in the grouping of the food categories, and adjustments in the selection of individuals whose consumption rates were used to develop the RMEI.

Table I-10. Average values of the dietary and lifestyle attributes for the RMEI.

Parameter	Mean value of the attribute
Leafy vegetables consumption rate (kilograms[a] per year)	3.9
Other vegetables consumption rate (kilograms per year)	4.8
Fruit consumption rate (kilograms per year)	12.4
Grain consumption rate (kilograms per year)	0.3
Meat consumption rate (kilograms per year)	2.6
Poultry consumption rate (kilograms per year)	0.4
Milk consumption rate (liters[b] per year)	4.8
Eggs consumption rate (kilograms per year)	5.6
Fish consumption rate (kilograms per year)	0.3
Water consumption rate (liters per year)	730
Inadvertent soil ingestion (milligrams[c] per day)	50
Inhalation exposure time (hours)	5,073.5
Soil exposure time (hours)	2,387

a. To convert kilograms to pounds, multiply by 2.2046.
b. To convert liters to gallons, multiply by 0.26417.
c. To convert milligrams to ounces, multiply by 0.000035274.

The biosphere dose conversion factors for the RMEI, characterized by the set of attributes listed in Table I-10, are given in Table I-11.

I.4.4.7 Igneous Activity Scenario

The model and parameter changes from TSPA–Site Recommendation to the model configuration used in the analysis for this EIS for the igneous activity scenario are described in detail in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Sections 13 and 14) and are summarized here.

Several input parameters to the TSPA models used to calculate consequences of igneous disruption changed after the TSPA–Site Recommendation and have been included in this analysis (DIRS 155950-

Table I-11. Biosphere dose conversion factors for the RMEI for the groundwater release and the volcanic release exposure scenarios.

Radionuclide	Groundwater release[a] (rem per picocurie per liter[b])	Volcanic release[a] (rem per picocurie per square meter[c])
Carbon-14	0.000029	NA[d]
Selenium-79	0.000012	3.8×10^{-11}
Strontium-90	0.0002	4.2×10^{-9}
Technetium-99	0.0000028	NA
Iodine-129	0.00025	NA
Cesium-137	0.00034	1.2×10^{-9}
Lead-210	0.0051	1.4×10^{-8}
Radium-226	0.005	4.2×10^{-9}
Actinium-227	0.013	1.9×10^{-6}
Thorium-229	0.0061	6.0×10^{-7}
Thorium-230	0.0012	9.1×10^{-8}
Protactinium-231	0.016	3.8×10^{-7}
Uranium-232	0.0018	1.9×10^{-7}
Uranium-233	0.00028	3.8×10^{-8}
Uranium-234	0.00027	3.8×10^{-8}
Uranium-236	0.00026	NA
Uranium-238	0.00026	NA
Neptunium-237	0.0045	1.9×10^{-7}
Plutonium -238	0.0029	1.1×10^{-7}
Plutonium-239	0.0035	1.3×10^{-7}
Plutonium -240	0.0035	1.3×10^{-7}
Plutonium-242	0.0032	1.2×10^{-7}
Americium-241	0.0035	1.3×10^{-7}
Americium-243	0.004	1.3×10^{-7}

a. Biosphere Dose Conversion Factors for the transition phase, 1 centimeter (0.4 inch) layer of ash and annual average mass loading
b. To convert liters to gallons, multiply by 0.26417.
c. To convert from square meters to square feet, multiply by 10.764.
d. NA = not applicable.

BSC 2001, Section 14.3.3.7). Consistent with new information regarding the probability of an eruption at the location of the proposed repository given an igneous intrusive event (DIRS 155950-BSC 2001, Section 14.3, all), the conditional probability of an eruption at the proposed repository was revised from 0.36 (DIRS 153246-CRWMS M&O 2000, Table 3.10-4, p. 198) to 0.77 (DIRS 155950-BSC 2001, Section 14.3.3.1, p. 14-13). According to *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (DIRS 151551-CRWMS M&O 2000, Section 6.5.3.2, and Table 12a, p. 130), the approach for the calculation of the conditional number of eruptive centers occurring within the repository footprint was modified by: 1) using empirical distributions for the average spacing between eruptive centers rather than the expected values for these distributions, and 2) incorporating uncertainty in the effect of the repository opening on the conditional probability of the occurrence of an eruptive center within the repository footprint. This modified approach resulted in the new conditional probability of 0.77 for one eruptive center to occur involving the Primary Block of the higher-temperature repository operating mode footprint during or coincident with an igneous activity event. This conditional probability has also been assumed for the lower-temperature operating mode analyses in Section I.5.

Changes also were made in the probability distribution for an intrusive event, consistent with revisions in the repository footprint (changes related to the higher-temperature operating mode) because inputs were compiled for TSPA–Site Recommendation. Revised distributions were provided for the number of waste packages affected by igneous intrusion and volcanic eruption events, consistent with the revised event probability information for the Primary Block of the higher-temperature operating mode. This adjusted event probability has also been assumed for the lower-temperature operating mode analyses in Section I.5. Changes have been made in the input data used to determine the wind speed during an eruption (DIRS 155950-BSC 2001, Section 3.3.1.2.1). Additional changes in inputs to the TSPA–Site Recommendation igneous consequence model are listed in *FY01 Supplemental Science and Performance Analyses*, Volume 1 (DIRS 155950-BSC 2001, Section 14.3.3.7, p. 14-24, and Tables 14.3.3.7-1 and 14.3.3.7-2, p. 14T-5 to 14T-6). Other model inputs and assumptions, including the assumption that wind direction would be fixed toward the location of the exposed individual at all times, were the same as those used in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 3.10).

I.4.4.8 Human Intrusion Scenario

The human intrusion scenario for the calculations in this EIS was developed from that in the TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 4.4). The model changes implemented for the human intrusion calculations in this EIS are described in this section.

Errata in the TSPA–Site Recommendation human intrusion model associated with “boosting” the inventory of certain radionuclides to account for first-generation decay product transport through the three-dimensional saturated zone model (DIRS 148384-CRWMS M&O 2000, Section 6.3.4.1, p. 233) were corrected.

In the TSPA–Site Recommendation human intrusion submodel (DIRS 148384-CRWMS M&O 2000, Section 6.3.9.3, p. 513), for the purpose of determining thermal-hydrologic conditions, in-package chemistry, and in-drift chemistry, the failed waste package was placed in a specified dripping environment for a given infiltration condition. For the calculations in this EIS, the failed waste package for each realization of the human intrusion scenario was randomly placed in one of several dripping environments depending on the infiltration condition.

Colloidal-facilitated transport of americium, plutonium, thorium, and protactinium in an exploratory borehole through the unsaturated zone has been included in the human intrusion scenario in this EIS. The decay products of irreversibly sorbed americium-241 and neptunium-237 were included as an irreversibly sorbed colloidal species. Colloidal-facilitated transport was implemented by adjusting the sorption coefficients of the aforementioned nuclides according to the relationship (DIRS 139440-CRWMS M&O 2000, p. 26):

$$K_d^{adj} = \frac{K_d^{orig}}{1 + K_c}$$

where

K_d^{orig} = sorption coefficient without colloidal-facilitated transport

K_d^{adj} = sorption coefficient with colloidal-facilitated transport

K_c = colloid partition coefficient

The human intrusion scenario in this EIS was simulated for a 1-million-year duration (as opposed to the 100,000-year duration in the TSPA–Site Recommendation). To be consistent with the *FY01 Supplemental Science and Performance Analyses* 1-million-year calculations, two additional radionuclides, radon-228 and thorium-232, were included in the inventory (DIRS 155950-BSC 2001, Section 13.2.1.10, pp. 13-9 and 13-10). The 30,000-year human intrusion scenario is the same scenario analyzed in the *FY01 Supplemental Science and Performance Analyses* (DIRS 155950-BSC 2001, Volume 1, Appendix A). The information in that appendix addresses the issue of when a human intrusion could occur based upon the earliest time that current technology and practices could lead to waste package penetration without the driller noticing waste package penetration. The earliest time would be that time (approximately 30,000 years) when the waste package had corroded sufficiently that a drill bit could penetrate it.

The assessment of the human intrusion scenario did not combine the results of this scenario with the results of the disruptive igneous activity scenario. However, combined results can be approximated by adding the results of the human intrusion calculations to the results of the disruptive igneous event scenario. Based on the results in Section I.5, the highest mean annual individual dose that would result from a human intrusion would be less than one-tenth of the radiological dose from a disruptive igneous event.

I.4.5 EXTENSION OF GROUNDWATER IMPACTS TO OTHER DISTANCES

The TSPA model described in Section I.2 was used to model the environmental impacts to groundwater for the long-term postclosure period. The TSPA model was originally developed to support the Yucca Mountain site suitability evaluation and possible subsequent licensing compliance analyses for the repository if the site was recommended. The model is, therefore, focused on the compliance requirements set forth in applicable regulations such as the Environmental Protection Agency standard, 40 CFR Part 197. This standard is concerned with a single compliance point, the RMEI location. The long-term impacts to groundwater predicted by the TSPA model would be restricted to that single location. Supporting models, such as the site-scale flow and transport model, were developed to support the TSPA calculation and do not extend much beyond the RMEI location. Furthermore, the TSPA made a conservative assumption that all radionuclide mass in groundwater would be captured in the water usage at the RMEI location. This is a reasonable approach for the compliance calculations because it tends to bias the concentration of materials to a higher value, without trying to account for complicated plume-capture considerations, and also because the volume of the plume passing this point in 1 year would be on the order of the upper bound of water usage. However, this assumption in the model does not allow it to account for the spreading of the plume at greater distances considered in this EIS.

As part of a comprehensive presentation of impacts, this EIS is charged with providing groundwater impacts for two other important downgradient locations. These are 30 kilometers (18 miles), where most of the current population in the groundwater path is located, and 60 kilometers (37 miles), where the aquifer discharges to the surface (also known as Franklin Lake Playa). The selection of these locations is discussed in Section I.4.5.1.

To provide insight about impacts at these other distances, a method of scaling was developed. This was necessary because the TSPA model is limited to the RMEI location, as described above. This section describes the approach to the scaling and the results obtained. The scaling approach is discussed in Section I.4.5.2 and the scaling factors in Section I.4.5.3.

I.4.5.1 Locations for Assessing Postclosure Impacts to Human Health

The Environmental Protection Agency public health and environmental radiation protection standards for Yucca Mountain (40 CFR Part 197) require DOE to estimate the potential radiation doses to the public from the disposal of spent nuclear fuel and high-level radioactive waste, based on the concept of the RMEI. This involves estimating the dose to a person assumed to be among those at greatest risk for 10,000 years after repository closure, given certain conservative exposure parameters and parameter value ranges. The Environmental Protection Agency selected a theoretical individual representative of a future population group or community, termed *rural-residential,* as the basis of an individual exposure scenario. This rural-residential RMEI would be exposed through the same general pathways as a subsistence farmer; however, the RMEI would not be a full-time farmer but rather would consume some locally grown food (self-grown or from local sources) as part of the exposure scenario. The Environmental Protection Agency also established a maximum 300-square-kilometer (74,000-acre)-controlled area, and established a RMEI location that equates to approximately 18 kilometers (11 miles) south of the repository (the predominant direction of groundwater flow), for demonstrating compliance with the long-term performance standards. The Environmental Protection Agency standard defines the postclosure accessible environment as being any point outside the controlled area.

For purposes of estimating potential environmental impacts in this EIS, DOE considered the impacts to the RMEI approximately 18 kilometers (11 miles) downgradient from the repository, as well as at other reasonable locations. In determining those locations, DOE considered locations where it would be reasonable from a technical and economic standpoint to locate a rural-residential individual. Although there exists a large number of locations at which analyses could be performed, DOE has determined that the most reasonable analyses to perform are for a rural-residential individual approximately 18, 30, and 60 kilometers (11, 19, and 37 miles) downgradient from the proposed repository, because these locations are based on realistic exposure conditions that would provide the basis for a meaningful comparison of potential human health impacts.

The Environmental Protection Agency, in reaching its conclusion on the location of the southernmost extent of the controlled area, considered current and projected uses of the land in the vicinity of the area formerly known as Lathrop Wells [now known as Amargosa Valley, approximately 20 kilometers (12 miles) downgradient from the repository]. The Agency noted there are currently eight residents and fewer than 10 businesses near this location whose source of water is the aquifer that flows beneath Yucca Mountain. This is the location where private property is nearest the proposed repository, and where some soils are suitable for agricultural purposes [the nearest farm is somewhat farther south, about 23 kilometers (14 miles) downgradient from the repository]. The Agency used near-term projections of land development between the current population at Amargosa Valley north to the Nevada Test Site. Near-term plans for the area between Amargosa Valley and the Test Site boundary include a science museum and industrial activities. Therefore, the boundary of the Test Site was used as the southernmost extent of the controlled area in 40 CFR 197.12. For this EIS, DOE adopted the southernmost extent of the controlled area as the RMEI location. This location is about 18 kilometers (11 miles) downgradient from the proposed repository.

DOE also has identified other reasonable locations for a hypothetical rural-residential individual approximately 30 and 60 kilometers (19 and 37 miles) downgradient from the repository. The closest population center is 30 kilometers (19 miles) downgradient in Amargosa Valley. At this location, the depth to groundwater suitable for human consumption and other uses (for example, agricultural) ranges from about 9 to 40 meters (30 to 130 feet) deep (less than that at the location formerly known as Lathrop Wells), and wells supply water to individual households. Franklin Lake Playa is about 60 kilometers (37 miles) downgradient from the proposed repository and is the location where the aquifer could emerge as surface water.

In conclusion, these three locations where a rural-residential individual could be reasonably located [about 18, 30, and 60 kilometers (11, 19, and 37 miles) downgradient] represent realistic locations where water for human consumption and other uses can occur using commonly available techniques without undue costs to withdraw and distribute water. These locations also reflect current populations and lifestyles in areas where dissolved radionuclides in the groundwater could affect future populations.

In the Draft EIS, DOE analyzed a Maximally Exposed Individual at a location 5 kilometers (3 miles) from the repository. The Maximally Exposed Individual was defined as a hypothetical person exposed to radiation in such a way—by a combination of factors including location, lifestyle, dietary habits, and so on—that the individual would be the most highly exposed member of the public. The Maximally Exposed Individual in the Draft EIS was a hypothetical member of a group of adults that would live in the Amargosa Valley with a characteristic range of lifestyle, food consumption, and groundwater usage patterns. This individual would grow half of the foods that the individual would consume on the property, irrigate crops and water livestock using groundwater, and use groundwater as a drinking water source and to bathe and wash clothes. The lifestyle and related exposure characteristics of the Maximally Exposed Individual are similar to those of the Environmental Protection Agency's rural-residential RMEI.

DOE noted in the Draft EIS that there are no permanent residents at a location 5 kilometers (3 miles) downgradient from the repository. The water table lies more than 360 meters (1,200 feet) deep in hard, volcanic rock. Although it might be possible, DOE would not expect permanent residents at that location in the future because of a lack of economically accessible groundwater. Human habitation has occurred in the vicinity of the repository where only the groundwater is easily accessible. Furthermore, the lands in this area are under the control of the Federal Government and within the controlled area defined in 40 CFR Part 197 – and thus are not part of the postclosure accessible environment.

In spite of these factors, DOE analyzed a Maximally Exposed Individual at a location 5 kilometers (3 miles) downgradient of the repository in the Draft EIS. At the time of the Draft EIS, Environmental Protection Agency had not published its draft or final radiation protection standards for Yucca Mountain, but DOE believed that a 5-kilometer compliance location could be established by the Environmental Protection Agency, given a similar compliance location in its generally applicable standards for the disposal of spent nuclear fuel, high-level radioactive waste and transuranic waste (40 CFR 191).

However, the Environmental Protection Agency has since published its final Yucca Mountain-specific public health and environmental radiation protection standards, and has concluded:

> "…it improbable that the rural-residential RMEI [reasonably maximally exposed individual] would occupy locations significantly north of U.S. Route 95 [location formerly known as Lathrop Wells], because the rough terrain and increasing depth to ground water nearer Yucca Mountain would likely discourage settlement by individuals because access to water is more difficult than it would be a few kilometers farther south."

The Environmental Protection Agency considered whether or not the inherent nature of the soils and the topography were conducive to or would constrain further development of the area near Yucca Mountain. The Agency concluded that:

> "…agricultural activity would be limited around Yucca Mountain as a result of adverse conditions, such as steep slopes, rocky terrain, and shallow soils…"

The Environmental Protection Agency also considered the potential dose to a RMEI at locations closer than approximately 18 kilometers (11 miles), and concluded that a rural-residential individual would receive a lower dose than those at 18 kilometers. The Agency stated that:

> "If individuals lived near the repository, they would be unlikely to withdraw water from the significantly greater depth for other than domestic use, and in the much larger quantities needed for gardening or farming activities because of the significant cost of finding and withdrawing the ground water. It is possible, therefore, for an individual located closer to the repository to incur exposures from contaminated drinking water, but not from ingestion of contaminated food. Based upon our analyses…we believe that use of contaminated ground water…would be the most likely pathway for most of the dose from the most soluble, more mobile radionuclides…The percentage of the dose that results from irrigation would depend upon assumptions about the fraction of all food consumed by the RMEI from gardening or other crops grown using contaminated water, which should reflect the

> lifestyle of current residents of the Town of Amargosa Valley. Therefore, the exposure of an RMEI located approximately 18 km south of the repository…actually would be more conservative than an RMEI located much closer to the repository…"

The Agency also addressed the economic feasibility of well drilling and pumping costs and concluded that:

> "…the capital costs of private wells for domestic use become prohibitive at depths between 300 and 600 feet. For communal domestic use and irrigation use, the capital costs do not become prohibitive even at depths of 1,200 feet…However, because of the very large volumes of water needed for irrigating field crops, particularly in the climate of Amargosa Valley, pumping costs are very significant for such agricultural applications. Combining the pumping cost estimates…with the capital cost estimates…the marginal value of water for irrigation is exceeded at depths to water greater than 300 feet. In fact, since these estimates do not consider the distribution cost for the irrigation system or any maintenance costs…it is not surprising to see that commercial agricultural activities in Amargosa Valley have been restricted thus far to areas where the depth to water is generally less than about 200 feet."

Based on the above considerations, DOE did not reevaluate the impacts at 5 kilometers (3 miles). This EIS contains evaluations of impacts at the RMEI location, at 30 kilometers (19 miles) downgradient from the repository (population center), and at the groundwater surface discharge point 60 kilometers (37 miles) downgradient from the repository.

I.4.5.2 Scaling Approach

This section summarizes the approach detailed in DIRS 157520-Williams (2001, Enclosure 3).

As the plume traveled over a given distance in the saturated zone, the concentration of radionuclides in the plume could be attenuated by several effects: dispersion, decay, filtration of solids by the aquifer medium, irreversible sorption of radionuclides by the aquifer medium, and other minor phenomena. The dispersion effects would be due to the combination of molecular diffusion and hydrodynamic mixing, that would tend to cause the contaminants to spread out along and transverse to the path of flow. The dispersion effect would reduce the peak concentration of the plume and increase the volume of the plume. The decay effect would be due to the later arrival of the plume centerline at a farther distance, allowing time for nuclear decay. The travel time would depend on the flow rate of the water and the retardation of contaminants that were sorbed reversibly by the aquifer solid media. The overall reduction by decay would be governed by the radionuclide travel time and the rate of decay of a particular radionuclide. The effects of colloid filtration, irreversible sorption, and other minor phenomena are expected to be small and are normally neglected. The principal radionuclides that would contribute to dose and most significantly affect groundwater quality have very long half-lives (and therefore very slow rates of decay), so the reduction of concentration by decay would be fairly small. The major contributor to the reduction of concentration in the contaminant plume, then, would be the dispersion effect. Therefore, the scaling approach was developed from only the dispersion effect. This produced a conservative result because the decay effect will cause some small additional reduction in concentration.

All of the major attenuating effects listed above were applied in the TSPA model for the calculation of the dose and water quality at the compliance point. However, because most of the path from the proposed repository to the compliance point is in the volcanic aquifer, there is only a small amount of dispersion. The volcanic aquifer is comprised mostly of fractured rock, so flow occurs in small isolated channels and mixing is minimal. This is why the plume is still small at the compliance point and full capture is a reasonable assumption. In the alluvial aquifer that extends from the RMEI location down to the discharge point, the aquifer medium is a finely divided, granular material where flow is slow and considerably more mixing can occur.

An analytical solution to the three-dimensional advection-dispersion problem was used to estimate dispersion effects from the RMEI location to the discharge point (DIRS 157520-Williams 2001, Enclosure 3, all). In these calculations, the groundwater flow velocity in the alluvium was assumed to be horizontal with a constant value of 18 meters (59 feet) per year, corresponding to a specific discharge rate of 2.7 meters (9 feet) per year and an effective porosity of 15 percent throughout the flow domain. These values were derived from the saturated zone site-scale model documented in DIRS 155950-BSC (2001, Section 12). Calculations were done under steady-state conditions, that is, for a source that has been discharging for a long time. The source was assumed to have constant concentration, be within a rectangular shape in the vertical plane, and centered at the repository location. Two source sizes were considered: a small source, 10 meters by 10 meters (33 feet by 33 feet), corresponding to an early failure scenario (localized failing waste package), and a large source, 3,000 meters (9,840 feet) horizontal by 10 meters (32.8 feet) vertical, corresponding to a long-term scenario in which all waste packages would fail.

The calculations were carried out for a range of dispersivities and for two assumed mass captures: 90 percent and 99 percent. The mass capture is a function of the amount of influence a well or field of wells would have in pulling mass from the plume. The results discussed here are restricted to the more conservative 99-percent capture assumption. Two important parameters were considered: the cross-section (perpendicular to flow) of the plume and the relative peak concentration at the center of the plume. As the plume traveled in the groundwater it would spread, so the cross-section would increase (thus reducing the average concentration) and the peak concentration would decrease. A reasonable approximation of distance effect can then be found by using either of these values. The two values will produce a slightly different result. Scaling factors using both approaches are discussed in the next section.

I.4.5.3 Scaling Factors for Dose or Water Quality Concentrations at Longer Distances

Table I-12 lists the resulting scaling factors from the dispersion studies (DIRS 157520-Williams 2001, Enclosure 3, Table 2a). The values are for the assumption of 99-percent capture, the larger realistic dispersion factor set, and two source sizes. The large source size would be applied for nominal scenario peak dose and the small source for localized sources such as the early failures (prior to 10,000 years) due to package defects or igneous intrusion releases, or for doses from the human intrusion scenario. Two sets of scaling factors are listed for each source size: one based on peak concentration and one based on plume cross-section. To obtain a value of dose or groundwater quality concentration at 30 or 60 kilometers (18 or 37 miles), multiply the 18-kilometer (11-mile) value by the appropriate scaling factor. The scaled results reported in Chapter 5, Section 5.4.1, use the plume cross-section factors. This is considered the best choice because the effect of water usage by the communities would be to cause significant mixing, and the more characteristic parameter would be the plume average concentration.

I.5 Waterborne Radioactive Material Impacts

The simulations in support of this analysis estimated the annual individual dose for the Proposed Action, Module 1, and Module 2 inventories. For the purposes of this EIS, DOE determined that the southern boundary of the controlled area would be at the southernmost point from the repository specified in 40 CFR Part 197 (36 degrees, 40 minutes, 13.6661 seconds north latitude). The RMEI location was then defined to be the point where the predominate groundwater flow crosses the boundary. Groundwater modeling indicated this point to be approximately 18 kilometers (11 miles) downgradient from the potential repository. This EIS refers to this location as the “RMEI location.” It corresponds to where the RMEI, a resident in an average farming community, would consume and use groundwater withdrawn from wells. In accordance with 40 CFR 197.35, the annual individual dose was calculated for the period of geologic stability (1 million years). These calculations include simulations for both the 10,000- and 1 million-year performance periods specified in 40 CFR 197.20 and 197.35.

An analytical solution to the three-dimensional advection-dispersion problem was used to estimate dispersion effects from the RMEI location to the discharge point (DIRS 157520-Williams 2001, Enclosure 3, all). In these calculations, the groundwater flow velocity in the alluvium was assumed to be horizontal with a constant value of 18 meters (59 feet) per year, corresponding to a specific discharge rate of 2.7 meters (9 feet) per year and an effective porosity of 15 percent throughout the flow domain. These values were derived from the saturated zone site-scale model documented in DIRS 155950-BSC (2001, Section 12). Calculations were done under steady-state conditions, that is, for a source that has been discharging for a long time. The source was assumed to have constant concentration, be within a rectangular shape in the vertical plane, and centered at the repository location. Two source sizes were considered: a small source, 10 meters by 10 meters (33 feet by 33 feet), corresponding to an early failure scenario (localized failing waste package), and a large source, 3,000 meters (9,840 feet) horizontal by 10 meters (32.8 feet) vertical, corresponding to a long-term scenario in which all waste packages would fail.

The calculations were carried out for a range of dispersivities and for two assumed mass captures: 90 percent and 99 percent. The mass capture is a function of the amount of influence a well or field of wells would have in pulling mass from the plume. The results discussed here are restricted to the more conservative 99-percent capture assumption. Two important parameters were considered: the cross-section (perpendicular to flow) of the plume and the relative peak concentration at the center of the plume. As the plume traveled in the groundwater it would spread, so the cross-section would increase (thus reducing the average concentration) and the peak concentration would decrease. A reasonable approximation of distance effect can then be found by using either of these values. The two values will produce a slightly different result. Scaling factors using both approaches are discussed in the next section.

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Table I-12. Groundwater impact distance scale factors[a,b] for 99-percent captured mass, longitudinal dispersivity 100 meters,[c] horizontal dispersivity 10 meters, and vertical dispersivity 0.1 meters.

	Scale factors	
Source	18 kilometers[d] to 30 kilometers	18 kilometers to 60 kilometers
Large source: 3,000 × 10 meters		
Based on plume cross-section	0.68	0.39
Based on relative peak concentration	0.74	0.46
Small source: 10 × 10 meters		
Based on plume cross-section	0.70	0.48
Based on relative peak concentration	0.60	0.30

a. Derived from DIRS 157520-Williams (2001, Enclosure 3, Table 2a).
b. To convert an 18-kilometer result to a 30- or 60-kilometer result, multiply the dose or the concentration by the appropriate value in the table.
c. To convert meters to feet, multiply by 3.281.
d. To convert kilometers to miles, multiply by 0.6214.

The calculations in this EIS also show the peak dose for all scenarios. The location is also where a representative volume of groundwater would be withdrawn and where there would be a reasonable expectation that radiation would not exceed the limits of 40 CFR 197.30, Table 1. This EIS also reports groundwater protection values at that location.

The data from the multiple realizations can be summarized by showing time versus annual individual dose (dose histories) for the 5th-percentile, median, mean, and 95th-percentile of the output. In the manner described for TSPA–Site Recommendation (DIRS 153246-CRWMS M&O 2000, Section 2.2.4.6, pp. 2-39 to 2-40), these statistical measures were calculated for all 300 realizations of the probabilistic simulations at each time step of the annual individual dose histories. The plot of the mean represents the average of all 300 data points at each time step. For each point on the plot of the median dose, 50 percent of the data have a value greater than the plotted point and 50 percent have a value less than the plotted point. Similarly, for the 5th- and 95th-percentiles, the plotted data points are such that 95 percent of data are greater than the plotted point and 5 percent of the data points are greater than the plotted points, respectively, for each time step. The statistical measures were superimposed on plots that show all 300 realizations (often referred to as “horsetail plots”).

I.5.1 WASTE PACKAGE FAILURE

Figure I-8 shows the waste package failure curves for the Proposed Action for the 1-million-year performance period for the higher-temperature operating mode. The figure indicates that the first waste package failures would occur within 10,000 years of repository closure. These early waste package failures result from the assumption of improper heat treatment (see Section I.2.4 and Table I-3). The 300 realizations are shown in Figure I-8. During the first 10,000 years there are some realizations showing a failure fraction of 0.00025, which when multiplied times the total waste packages (11,770) gives a maximum of 3 early waste package failures. There are some realizations that show zero failures, but this is not readily evident from the figure. Waste package failure would be the first step in releasing radionuclides for groundwater flow and transport.

Figure I-9 shows cladding perforated during the postclosure period. The calculations included the averaged impact of seismic events. The cladding failure results shown in Figure I-9 are essentially the same as those developed in the *FY01 Supplemental Science and Performance Analyses* (DIRS 154659-BSC 2001, pp. 9-19 to 9-23).

I.5.2 ANNUAL INDIVIDUAL DOSE FOR 10,000 YEARS AFTER CLOSURE

This section presents graphic representations of annual individual doses for the inventories described in Section I.3 and the scenarios described in Section I.4. The performance period for the calculations in this EIS was generally 1 million years after repository closure except in the case of the igneous activity scenarios. The annual dose histories for the igneous activity scenarios were only calculated for 100,000 years after closure because the releases from the nominal scenario dominate after that time. In addition to the graphic presentations, Table I-13 lists the values of the peak mean annual individual dose for all scenarios that would occur in the 10,000-, 100,000-, and 1-million-year postclosure performance periods, in accordance with 40 CFR 197.20, 197.25, and 197.35. Table I-14 lists the same information for the peak 95th-percentile annual individual dose.

Table I-13. Peak mean annual individual doses (millirem) for analyzed inventories, scenarios, and temperature operating modes.[a,b]

Modeled inventory, scenario, and operating mode	10,000 years		100,000 years		1 million years	
	Value	Year	Value	Year	Value	Year
Proposed Action, nominal, higher-temperature	0.000017	4,875	0.12	99,500	152.5	476,000
Proposed Action, nominal lower-temperature	0.000011	3,437.5	0.085	99,500	122.2	476,000
Inventory Module 1, nominal, higher-temperature	0.000027	4,937.5	0.16	100,000	237.9	476,000
Inventory Module 2, nominal, higher-temperature[c]	0.00066	2,875	0.00066	2,875	0.33	208,000
Proposed Action, igneous activity, higher-temperature	0.10	312.5	0.10	312.5	NC[d]	NC
Proposed Action, igneous activity, lower-temperature	0.10	312.5	0.10	312.5	NC	NC
Proposed Action, igneous activity (intrusive only), higher-temperature	0.00043	10,000	0.021	48,000	NC	NC
Proposed Action, igneous activity (intrusive only), lower-temperature	0.00050	10,000	0.028	48,000	NC	NC
Proposed Action, igneous activity (eruptive only), higher-temperature	0.10	312.5	0.10	312.5	NC	NC
Proposed Action, igneous activity (eruptive only), lower-temperature	0.10	312.5	0.10	312.5	NC	NC
Proposed Action, human intrusion at 30,000 years, higher-temperature	NA[e]	NA	0.0017	30,562.5	0.0023	108,000

a. Adapted from DIRS 157307-BSC (2001, Enclosure 1).
b. These data are based on the same probabilistic annual water usage model used in the TSPA–Site Recommendation (not 3,000 acre-feet per year).
c. Module 2 runs only included the incremental effect of the additional inventory from Greater-Than-Class-C and Special-Performance-Assessment-Required waste.
d. NC = not calculated.
e. NA = not applicable.

I.5.3 ANNUAL INDIVIDUAL DOSE FOR 1,000,000 YEARS AFTER CLOSURE

Results for annual individual dose calculations for 1 million years following closure are discussed for the Proposed Action (Section I.5.3.1), Inventory Module 1 (Section I.5.3.2) and Inventory Module 2 (Section I.5.3.3).

Table I-14. Peak 95th-percentile annual individual doses (millirem) for analyzed inventories, scenarios, and temperature operating modes.[a,b]

Modeled inventory, scenario, and operating mode	10,000 years		100,000 years		1,000,000 years	
	Value	Year	Value	Year	Value	Year
Proposed Action, nominal, higher-temperature	0.00012	4,937.5	0.040	99,500	618.0	408,000
Proposed Action, nominal, lower-temperature	0.000086	5,000	0.034	100,000	513.2	408,000
Inventory Module 1, nominal, higher-temperature	0.00018	4,125	0.079	100,000	976.7	476,000
Inventory Module 2, nominal, higher-temperature[c]	0[d]	NA[e]	0.0013	100,000	1.5	208,000
Proposed Action, igneous activity, higher-temperature	0.41	312.5	0.41	312.5	NC[f]	NC
Proposed Action, igneous activity, lower-temperature	0.41	312.5	0.41	312.5	NC	NC
Proposed Action, igneous activity (intrusive only), higher-temperature	0.00029	9,750	0.052	100,000	NC	NC
Proposed Action, igneous activity (intrusive only), lower-temperature	0.00031	9,875	0.033	48,000	NC	NC
Proposed Action, igneous activity (eruptive only), higher-temperature	0.41	312.5	0.41	312.5	NC	NC
Proposed Action, igneous activity (eruptive only), lower-temperature	0.41	312.5	0.41	312.5	NC	NC
Proposed Action, human intrusion at 30,000 years, higher-temperature	NA	NA	0.0045	38,500	0.0045	38,400

a. Adapted from DIRS 157307-BSC 2001, Enclosure 1.
b. These data are based on the same probabilistic annual water usage model used in the TSPA–Site Recommendation (not 3,000 acre-feet per year).
c. Module 2 runs only included the incremental effect of the additional inventory from Greater-Than-Class-C and Special-Performance-Assessment-Required waste.
d. The mean dose is driven by 3 realizations that experience early failures; no other realizations result in a dose before 10,000 years so that the 95th-percentile value is zero.
e. NA = not applicable.
f. NC = not calculated.

I.5.3.1 Annual Individual Dose for the Proposed Action Inventory, Higher- and Lower-Temperature Repository Operating Modes

Figure I-10 shows the mean annual individual dose results of the 300 probabilistic simulations for the higher-temperature repository operating mode (approximately 56 MTHM per acre) for the Proposed Action inventory at the RMEI location for 1 million years after repository closure. Figure I-11 shows the relative contribution of selected radionuclides that contribute most to the total mean annual dose due to all radionuclides. Figure I-12 shows the results of the 300 probabilistic simulations of the Proposed Action inventory, higher-temperature operating mode, at the RMEI location for 1 million years after repository closure. This figure shows the results for each realization and the 5th-percentile, mean, median, and 95th-percentile of these simulations.

Figure I-10 also shows representations of the mean annual individual dose results of the 300 probabilistic simulations for the lower-temperature operating mode (approximately 45 MTHM per acre) for the Proposed Action inventory at the RMEI location for 1 million years after repository closure. Because Figure I-10 shows little difference between the annual individual dose histories calculated for the higher-temperature and the lower-temperature operating modes, the remaining scenarios, other than the igneous activity scenario, were simulated only for the higher-temperature operating mode. Figure I-13 shows the results of the 300 probabilistic simulations of the Proposed Action inventory, lower-temperature operating mode, at the RMEI location for 1 million years after repository closure. This figure shows the results for each realization and the 5th-percentile, mean, median, and 95th-percentile of these simulations.

I.5.3.2 Annual Individual Dose for Inventory Module 1, Higher-Temperature Repository Operating Mode

Figure I-14 displays the annual dose histories for the 300 probabilistic simulations of the expanded-inventory Module 1, higher-temperature operating mode at the RMEI location for 1 million years after repository closure. This figure shows the results for each realization and the 5th-percentile, mean, median, and 95th-percentile of these simulations.

I.5.3.3 Annual Individual Dose for Inventory Module 2, Higher-Temperature Repository Operating Mode

A GoldSim simulation was performed for a case that included only the Greater-Than-Class-C and Special-Performance-Assessment-Required components of the Module 2 inventory. The case did not include the other components of the Module 2 inventory (that is, the Module 1 inventory). The GoldSim simulation for only the Module 2 Greater-Than-Class-C and Special-Performance-Assessment-Required inventory, higher-temperature operating mode, was performed as a separate probabilistic case at the RMEI location. Figure I-15 shows the results of this simulation as the mean annual individual dose due to the radioactive components of this material. The effects of nonradioactive components of this waste are not included in the analysis.

Figure I-16 is a comparison plot of the mean annual dose versus time for the Proposed Action, Module 1, and the Greater-Than-Class-C and Special-Performance-Assessment-Required waste portion of the Module 2 inventories at the higher-temperature operating mode at the RMEI location. These results show that during the first 10,000 years, the mean annual individual dose due to the Greater-Than-Class-C and Special-Performance-Assessment-Required components of the Module 2 inventory would be greater than that calculated for the Proposed Action and Module 1 inventories, but still essentially zero. After 10,000 years, the dose due to the Greater-Than-Class-C and Special-Performance-Assessment-Required components of the Module 2 inventory would be about two orders of magnitude less than that calculated for the Proposed Action and Module 1 inventories. These results indicate that the addition of the Greater-Than-Class-C and Special-Performance-Assessment-Required waste to the Module 1 inventory would not materially increase the mean annual individual dose. Based on this comparison, separate probabilistic simulations were not run for the entire Inventory Module 2.

I.5.3.4 Annual Individual Dose for Igneous Activity Scenario, Higher- and Lower-Temperature Repository Operating Modes

The performance of a Yucca Mountain repository was evaluated for a combined igneous activity scenario that included both an igneous event and a volcanic eruption. The combined scenario was simulated for the higher- and lower-temperature repository operating modes for the Proposed Action inventory. Annual dose histories were not calculated for the igneous activity scenario for Modules 1 and 2.

Figure I-17 shows representations of the probability-weighted annual individual dose histories for 500 of the 5,000 probabilistic simulations for the igneous activity scenario, higher-temperature repository operating mode (approximately 56 MTHM per acre) for the Proposed Action inventory at the RMEI location for 100,000 years after repository closure. Figure I-17 also shows the 5th-percentile, mean, median, and 95th-percentile of all 5,000 igneous activity simulations. The results shown in the figure represent the combined effect of both the igneous-intrusion and eruptive events.

Figure I-18 shows the mean annual individual dose versus time for the igneous activity scenario for the Proposed Action inventory for the higher-temperature operating mode at the RMEI location. The figure also shows the mean results for both the eruptive and intrusive events. Figure I-19 shows the mean annual individual dose for the igneous activity scenarios, representing the sum of the igneous and eruptive events, Proposed Action inventory for the higher- and lower-temperature operating modes at the RMEI location.

Figure I-20 shows representations of the probability-weighted annual individual dose histories for 500 of the 5,000 probabilistic simulations for the igneous activity scenario, lower-temperature repository operating mode (approximately 45 MTHM per acre) for the Proposed Action inventory at the RMEI location for 100,000 years after repository closure. Figure I-20 also shows the 5th-percentile, mean, median, and 95th-percentile of all 5,000 igneous activity simulations. The results presented in this figure represent the combined effect of both the igneous intrusion and eruptive events.

Figure I-21 shows the mean individual annual dose versus time for the igneous activity scenario for the Proposed Action inventory for the lower-temperature repository operating mode at the RMEI location. The figure also displays the mean results for both the eruptive and intrusive events.

I.5.3.5 Annual Individual Dose for the Human Intrusion Scenario

Figure I-22 displays representations of the annual individual dose results of the 300 probabilistic simulations for the human intrusion scenario, 30,000 years after repository closure, Proposed Action inventory for the higher-temperature operating mode at the RMEI location. Figure I-22 displays the results for each simulation and the 5th-percentile, median, mean, and 95th-percentile of these simulations.

I.5.4 COMPARISON TO GROUNDWATER PROTECTION STANDARDS

An analysis for groundwater protection was conducted in accordance with the Environmental Protection Agency Final Rule 40 CFR 197.30 and 197.31). The rule is based on meeting three groundwater radionuclide-concentration levels. The first is the maximum annual concentration of radium-226 and -228 in a representative volume of 3.7 million cubic meters (3,000 acre-feet) of groundwater in a release from the proposed repository. The second groundwater concentration is for the gross alpha activity (excluding radon and uranium) in the representative volume of groundwater. Both calculations apply to releases from both natural sources and releases from the repository at the same location as the RMEI. The third groundwater-protection calculation is the dose to the whole body or any organ of a human for beta- and photon-emitting radionuclides released from the repository. The human would consume 2.0 liters (0.53 gallon) per day from the representative volume of groundwater. This groundwater would be withdrawn annually from an aquifer containing less than 10,000 milligrams per liter (1.34 ounces per gallon) of total dissolved solids, and centered on the highest concentration in the plume of contamination at the same location as the RMEI. The results of the calculations for this EIS produced data consistent with the Environmental Protection Agency Final Rule and are presented graphically and in tabular form.

Figure I-23 shows the mean activity concentrations of gross alpha activity and total radium (radium-226 plus radium-228) in the representative volume of groundwater for the Proposed Action inventory, higher-temperature repository operating mode. The concentrations are calculated for a representative volume of water of 3.7 million cubic meters (exactly 3,000 acre-feet per year) at the same location as the RMEI at the accessible environment as described in 40 CFR 197.30. Naturally occurring background radionuclide concentrations were not included because the calculated values are negligible compared to background concentrations up to 100,000 years after closure. Figure I-24 shows the same information for the lower-temperature operating mode.

Figure I-25 shows the mean dose to the whole body or any organ for technetium-99, carbon-14, and iodine-129, the prominent beta and photon-emitting radionuclides (DIRS 154659-BSC 2001, Volume 2, Section 4.1.4, pp. 4 to 11) for the Proposed Action inventory, higher-temperature repository operating mode, for the 1-million-year performance period. Figure I-26 shows the same information for the lower-temperature operating mode.

The data developed for the groundwater protection standard are summarized in Table I-15, which lists the peak mean gross alpha activity by scenario for various performance periods; Table I-16, which lists peak total radium concentration by scenario for various performance periods; and Table I-17, which lists the combined whole-body or organ doses in 10,000 years for the total of all beta- and photon-emitting radionuclides. The mean whole-body or organ dose was calculated by diluting the model-predicted annual activity releases of iodine-129, carbon-14, and technetium-99 [the prominent beta and photon-emitting radionuclides (DIRS 154659-BSC 2001, Volume 2, Section 4.1.4, pp. 4 to 11)] in the representative volume of groundwater (3,000 acre-feet per year). The resulting concentrations for each time step were converted to equivalent doses by scaling the appropriate dose conversion factor (4 millirem per 2,000 picocurie per liter for carbon-14; 4 millirem per 1 picocurie per liter for iodine-129; and 4 millirem per 900 picocurie for technetium 99). Calculating the sum of these three radionuclide doses for each time step produced a time history of whole-body or organ dose; the peak within 10,000 years was identified and is reported in Table I-17. This process is repeated for 95th-percentile whole-body or organ dose using model-predicted 95th-percentile annual activity releases of the prominent beta and photon-emitting radionuclides.

I.6 Waterborne Chemically Toxic Material Impacts

Several materials that are chemically toxic would be used in the construction of the repository. A screening analysis was used to determine which, if any, of these materials would have the potential to be transported to the accessible environment in quantities sufficient to be toxic to humans.

Chemicals included in the substance list for the Environmental Protection Agency's Integrated Risk Information System (DIRS 103705-EPA 1997, all; DIRS 148219, 148221, 148224, 148227, 148228, 148229, and 148233-EPA 1999, all) were evaluated to determine a concentration that would be found in drinking water in a well downgradient from the repository. The chemicals on the Integrated Risk Information System substance list that would be in the repository are barium, boron, cadmium, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium, uranium, vanadium, and zinc.

I.6.1 SCREENING ANALYSIS

The results of the analysis of long-term performance for radionuclides detailed in Section I.5 show that, at most, three waste packages would be breached prior to 10,000 years (due to improper heat treatment) under the Proposed Action. The period of consideration for chemical toxic materials impacts was 10,000 years. Therefore, only toxic materials outside the waste package were judged to be of concern in this analysis. These are chromium, copper, manganese, molybdenum, nickel, and vanadium.

I.6.1.1 Maximum Source Concentrations of Chemically Toxic Materials in the Repository

Maximum source concentrations were calculated to provide the maximum possible concentration of that element in water entering the unsaturated zone. For materials that were not principally part of the Alloy-22 (copper and manganese), the maximum source concentration was taken to be the solubility of the material in repository water. The solubilities were obtained by modeling with the EQ3 computer code (DIRS 100836-Wolery 1992, all). The simulations were started with water from well J-13 near the Yucca Mountain site (DIRS 100814-Harrar et al. 1990, all). EQ3 calculates chemical equilibrium of a system so that, by making successive runs with gradually increasing aqueous concentrations of an element,

Figure I-25 shows the mean dose to the whole body or any organ for technetium-99, carbon-14, and iodine-129, the prominent beta and photon-emitting radionuclides (DIRS 154659-BSC 2001, Volume 2, Section 4.1.4, pp. 4 to 11) for the Proposed Action inventory, higher-temperature repository operating mode, for the 1-million-year performance period. Figure I-26 shows the same information for the lower-temperature operating mode.

The data developed for the groundwater protection standard are summarized in Table I-15, which lists the peak mean gross alpha activity by scenario for various performance periods; Table I-16, which lists peak total radium concentration by scenario for various performance periods; and Table I-17, which lists the combined whole-body or organ doses in 10,000 years for the total of all beta- and photon-emitting radionuclides. The mean whole-body or organ dose was calculated by diluting the model-predicted annual activity releases of iodine-129, carbon-14, and technetium-99 [the prominent beta and photon-emitting radionuclides (DIRS 154659-BSC 2001, Volume 2, Section 4.1.4, pp. 4 to 11)] in the representative volume of groundwater (3,000 acre-feet per year). The resulting concentrations for each time step were converted to equivalent doses by scaling the appropriate dose conversion factor (4 millirem per 2,000 picocurie per liter for carbon-14; 4 millirem per 1 picocurie per liter for iodine-129; and 4 millirem per 900 picocurie for technetium 99). Calculating the sum of these three radionuclide doses for each time step produced a time history of whole-body or organ dose; the peak within 10,000 years was identified and is reported in Table I-17. This process is repeated for 95th-percentile whole-body or organ dose using model-predicted 95th-percentile annual activity releases of the prominent beta and photon-emitting radionuclides.

I.6 Waterborne Chemically Toxic Material Impacts

Several materials that are chemically toxic would be used in the construction of the repository. A screening analysis was used to determine which, if any, of these materials would have the potential to be transported to the accessible environment in quantities sufficient to be toxic to humans.

Chemicals included in the substance list for the Environmental Protection Agency's Integrated Risk Information System (DIRS 103705-EPA 1997, all; DIRS 148219, 148221, 148224, 148227, 148228, 148229, and 148233-EPA 1999, all) were evaluated to determine a concentration that would be found in drinking water in a well downgradient from the repository. The chemicals on the Integrated Risk Information System substance list that would be in the repository are barium, boron, cadmium, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium, uranium, vanadium, and zinc.

I.6.1 SCREENING ANALYSIS

The results of the analysis of long-term performance for radionuclides detailed in Section I.5 show that, at most, three waste packages would be breached prior to 10,000 years (due to improper heat treatment) under the Proposed Action. The period of consideration for chemical toxic materials impacts was 10,000 years. Therefore, only toxic materials outside the waste package were judged to be of concern in this analysis. These are chromium, copper, manganese, molybdenum, nickel, and vanadium.

I.6.1.1 Maximum Source Concentrations of Chemically Toxic Materials in the Repository

Maximum source concentrations were calculated to provide the maximum possible concentration of that element in water entering the unsaturated zone. For materials that were not principally part of the Alloy-22 (copper and manganese), the maximum source concentration was taken to be the solubility of the material in repository water. The solubilities were obtained by modeling with the EQ3 computer code (DIRS 100836-Wolery 1992, all). The simulations were started with water from well J-13 near the Yucca Mountain site (DIRS 100814-Harrar et al. 1990, all). EQ3 calculates chemical equilibrium of a system so that, by making successive runs with gradually increasing aqueous concentrations of an element,

Table I-15. Peak mean gross alpha activity for analyzed inventories, scenarios, and temperature operating modes.[a,b]

Modeled inventory, scenario[c], and operating mode	10,000 years		100,000 years		1 million years	
	Without background	With background[d]	Without background	With background	Without background	With background
Proposed Action, nominal, higher-temperature	1.8×10^{-8}	0.40	0.017	0.42	17.7	18.1
Proposed Action, nominal, lower-temperature	3.3×10^{-8}	0.40	0.010	0.41	14.2	14.6
Inventory Module 1, nominal, higher-temperature	3.3×10^{-8}	0.40	0.023	0.42	27.7	28.1
Inventory Module 2, nominal, higher-temperature	2.2×10^{-10}	0.40	0.000042	0.40	0.039	0.44
Proposed Action, human intrusion event at 30,000 years, higher-temperature	NA[e]	NA	0.00018	0.40	0.00031	0.40

a. Adapted from DIRS 157307-BSC (2001, Enclosure 1).
b. These results are based on an annual water usage equal to 3.7 million cubic meters (exactly 3000 acre-feet) per year.
c. Mean gross alpha activity is not available for igneous activity scenarios
d. Background alpha activity concentration is 0.4 picocurie per liter.
e. NA = not applicable.

Table I-16. Peak mean total radium concentration (picocuries per liter) for analyzed inventories, scenarios, and temperature operating modes.[a,b]

Modeled inventory, scenario[c], and operating mode	10,000 years		100,000 years		1 million years	
	Without background	With background[d]	Without background	With background	Without background	With background
Proposed Action, nominal, higher-temperature	1.1×10^{-11}	1.0	2.4×10^{-5}	1.0	0.33	1.4
Proposed Action, nominal, lower-temperature	2.4×10^{-12}	1.0	2.7×10^{-5}	1.0	0.27	1.3
Inventory Module 1, nominal, higher-temperature	3.3×10^{-10}	1.0	4.0×10^{-5}	1.0	0.67	1.7
Inventory Module 2, nominal, higher-temperature	6.7×10^{-13}	1.0	6.8×10^{-9}	1.0	0.0016	1.0
Proposed Action, human intrusion event at 30,000 years, higher-temperature	NA[e]	NA	2.4×10^{-7}	1.0	3.8×10^{-7}	1.0

a. Adapted from DIRS 157307-BSC (2001, Enclosure 1).
b. These results are based on an annual water usage equal to 3.7 million cubic meters (exactly 3000 acre-feet) per year.
c. Total radium concentration is not available for igneous activity scenarios
d. Background radium activity concentration is 1.04 picocuries per liter.
e. NA = not applicable.

Table I-17. Peak mean annual whole body or organ dose (millirem)[a] for the sum of all beta- and photon-emitting radionuclides during 10,000 years after closure for analyzed inventories, scenarios, and temperature operating modes.[b]

Modeled inventory, scenario and operating mode	Total
Proposed Action, nominal, higher-temperature	2.3×10^{-5}
Proposed Action, nominal, lower-temperature	1.3×10^{-5}
Proposed Action, human intrusion event at 30,000 years, higher-temperature	NA[c]
Inventory Module 1, nominal, higher-temperature operating mode	2.8×10^{-5}

a. This represents a bounding limit (overestimate) of the maximum dose to any organ because different radionuclides would affect different organs preferentially.
b. These results are based on an annual water usage equal to 3.7 million cubic meters (exactly 3000 acre-feet) per year.
c. NA = not applicable.

eventually a result will show the saturation of a mineral in that element. That concentration at which the first mineral saturates is said to be the "solubility." The solubility of copper (from the electrical bus bars left in the tunnels) was obtained by increasing copper concentrations in successive runs of EQ3. At a concentration of 0.018 milligram per liter, copper began to precipitate as tenorite (CuO). This mineral was then in equilibrium with dissolved copper existing in approximately equal molar parts as $CuOH^+$, $Cu(CO_3)$aq, and Cu^{++}. A similar approach for manganese gave a solubility of 4.4×10^{-10} milligram per liter as pyrolusite (MnO_2) began to precipitate. In the cases of chromium, molybdenum, nickel, and vanadium, the source concentration has a potential to be very high because the corrosion of Alloy-22 could result in a very low pH solution (much different from the repository water). Thus, for purposes of screening, it was assumed that these materials had a potentially very high source concentration and should be subjected to further screening analysis (this is discussed in Section I.6.2).

I.6.1.2 Further Screening for Chemically Toxic Materials

Manganese was further analyzed using a comparison of intake to the Oral Reference Dose. The Oral Reference Dose is an indication of the limit for possible health effects from oral ingestion. Intake was based on a 2-liter (0.53-gallon) daily consumption rate of drinking water, at the maximum source concentrations (solubilities), by a 70-kilogram (154-pound) adult. Calculation takes no credit for any dilution from the source to the recipient. For manganese, the intake would be 2.2×10^{-12} milligram per kilogram per day. This is very small compared to the Oral Reference Dose of 0.14 milligram per kilogram per day listed for manganese in the Integrated Risk Information System (DIRS 148227-EPA 1997, all). Thus, it is concluded that manganese requires no further consideration.

No Oral Reference Dose is available for copper, but a similar evaluation can be made by comparing the maximum source concentration to a maximum concentration limit for the drinking water standard (40 CFR 141.2). For copper the maximum contaminant limit is 1.3 milligrams per liter. This is much higher than the source concentration of 0.018 milligram per liter, so it is concluded that copper requires no further consideration.

ORAL REFERENCE DOSE

The *Oral Reference Dose* is based on the assumption that thresholds exist for certain toxic effects such as cellular necrosis. This dose is expressed in units of milligrams per kilogram per day. In general, the oral reference dose is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (DIRS 148219-EPA 1999, all).

The remaining hazardous elements of concern (chromium, molybdenum, nickel, and vanadium) are analyzed in the next section.

I.6.2 BOUNDING CONSEQUENCE ANALYSIS FOR CHEMICALLY TOXIC MATERIALS

Further evaluation is warranted because the first level of the screening analysis (Section I.6.1) indicated that the repository could release certain waterborne chemically toxic materials into groundwater in substantial quantities and that these could represent a potential human health impact. The following materials require further evaluation: chromium, molybdenum, nickel, and vanadium. A bounding calculation for concentrations in the biosphere is presented in this section for these elements that shows the impacts would be low enough to preclude any need for more detailed fate and transport analyses.

I.6.2.1 Assumptions

The following assumptions were applied to the bounding impact analysis for waterborne chemically toxic materials:

1. The general corrosion rate of Alloy-22 is equivalent for humid-air and aqueous corrosion conditions (this assumption is consistent with treatment of this substance in the TSPA–Site Recommendation).

2. The general corrosion rate of Alloy 316NG (stainless steel) is also equivalent for humid air and aqueous corrosion conditions.

3. Consistent with Assumptions 1 and 2 above, drip shields were not assumed to effectively delay onset of general corrosion of Alloy-22 in the outer barrier layer of waste packages or the emplacement pallets.

4. Consistent with Assumptions 1, 2, and 3 above, exposed Alloy-22 and stainless steel 316NG in the drip shield rail, waste packages, and emplacement pallets would all be subject to corrosion at the same time.

5. Consistent with Assumptions 1, 2, and 3 above, all waste packages would be subject to general corrosion at the same time, and would not experience variability in the time corrosion begins.

6. The median corrosion rates for Alloy-22 and stainless steel 316NG were used in the impact estimate calculations because the rates apply to all waste packages, drip shields, and emplacement pallets in the repository.

7. A migration pathway for mobilized waterborne chemically toxic materials through the engineered barrier system to the vadose zone was assumed to exist at all times general corrosion is in progress.

8. Time delays, mitigation effects by sorption in rocks, and other beneficial effects of transport in the geosphere were neglected for purposes of this bounding impact estimate; the mass of waterborne chemically toxic materials mobilized was assumed to be instantly available at the biosphere exposure locations.

9. The concentration in groundwater was estimated by diluting the released mass of waterborne chemically toxic materials in the representative volume defined by the Environmental Protection Agency [3.7 million cubic meters (exactly 3,000 acre-feet) of water per year] in 40 CFR Part 197.

10. Under the chemical environment of the waste package, all chromium, molybdenum, nickel, and vanadium were assumed to be in their most soluble and toxic state. This is a highly conservative assumption but is consistent with other modeling of the waste package chemical environment.

11. Mobilization of chromium, molybdenum, nickel, and vanadium was assumed equivalent to the corrosion loss of stainless steel or Alloy-22 times the fraction of each element in the alloys.

12. Throughout the discussions in Section I.6.2 it is assumed that the form of mobilized chromium is the hexavalent form. The hexavalent form of chromium [Cr(VI)] is considered potentially hazardous, whereas the more common corrosion product, trivalent chromium [Cr(III)], is not. This is a conservative assumption because DOE believes that most of the mobilized Cr would be the trivalent form.

I.6.2.2 Surface Area Exposed to General Corrosion

Corrosion of the materials bearing chromium and molybdenum would occur over all exposed surface areas. The total exposed surface area of Alloy-22 surfaces (drip shield rails, outer layer of waste packages, and portions of the emplacement pallets) and stainless-steel 316NG surfaces (portions of the emplacement pallets) are calculated in this section.

Tables I-18 and I-19 summarize the calculation of the total exposed surface areas for Alloy-22 contained in the waste packages and drip shields, respectively, under the Proposed Action.

Table I-18. Total exposed surface area of the Alloy-22 outer layer of all waste packages under the Proposed Action inventory.

Waste package type[a]	Number[b]	Outer diameter[a] (millimeters)[b]	Length[a] (millimeters)[b]	Surface area[c] (square millimeters)[d]	Total surface area (square meters)[e]
21 PWR absorber plate	4,299	1,664	5,165	31,349,978	134,774
21 PWR control rods	95	1,664	5,165	31,349,978	2,978
12 PWR absorber plate	163	1,330	5,651	26,390,258	4,302
44 BWR absorber plate	2,831	1,674	5,165	31,564,675	89,360
24 BWR thick absorber plate	84	1,318	5,105	23,866,529	2,005
5 DHLW/DOE SNF	1,592	2,110	3,590	30,790,593	49,019
5 DHLW/DOE SNF–long	1,751	2,110	5,217	41,575,586	72,799
Navy SNF	200	1,949	5,430	39,214,523	7,843
Navy SNF–long	100	1,949	6,065	43,102,606	4,310
2 MCO/2 HLW	186	1,815	5,217	34,921,842	6,495
Totals	***11,301***				***373,884***

a. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
b. To convert millimeters to inches, multiply by 0.0394.
c. Surface area calculated as area of a right circular cylinder.
d. To convert square millimeters to square inches, multiply by 0.00155.
e. To convert square meters to square feet, multiply by 10.764.

Table I-19. Total exposed surface area of the Alloy-22 rails for all drip shields under the Proposed Action inventory.

Component	Number of pieces	Average waste package emplacement length[a] (millimeters)[b]	Width[c] (millimeters)[d]	Thickness[c] (millimeters)	Total surface area per average waste package[e] (square millimeters[f])	Number of waste packages[c]	Total surface area for repository (square meters[g])
Rail	2	5,076	115	10	1,370,520	11,301	15,488

a. Emplacement length estimate from DIRS 155393-CRWMS M&O (2000, Attachment V, p. V-2).
b. To convert meters to feet, multiply by 3.2808.
c. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
d. To convert millimeters to inches, multiply by 0.0394.
e. Surface area calculated as sum of areas of wetted surfaces (two rectangles) of angles running along the bottom of both sides of the drip shield.
f. To convert square millimeters to square inches, multiply by 0.00155.
g. To convert square meters to square feet, multiply by 10.764.

Tables I-20 and I-21 summarize the calculation of the total exposed surface areas for Alloy-22 contained in the waste packages and drip shields, respectively, for the Module 1 inventory.

Tables I-22 and I-23 summarize the calculation of the total exposed surface areas for Alloy-22 contained in the waste packages and drip shields respectively, for the Module 2 inventory.

Table I-24 summarizes the calculation of total exposed surface area for the Alloy-22 components of the emplacement pallets for the Proposed Action, Module 1, and Module 2 inventories.

Table I-20. Total exposed surface area of the Alloy-22 outer layer of all waste packages for the Module 1 inventory.

Waste package type	Number[a]	Outer diameter[a] (millimeters)[b]	Length[a] (millimeters)	Surface area[c] (square millimeters)[d]	Total surface area (square meters)[e]
21 PWR absorber plate	6,733	1,664	5,165	31,349,978	211,079
21 PWR control rods	114	1,664	5,165	31,349,978	3,574
12 PWR absorber plate	390	1,330	5,651	26,390,258	10,292
44 BWR absorber plate	4,408	1,674	5,165	31,564,675	139,137
24 BWR thick absorber plate	109	1,318	5,105	23,866,529	2,601
5 DHLW/DOE SNF	1,557	2,110	3,590	30,790,593	47,941
5 DHLW/DOE SNF–long	2,821	2,110	5,217	41,575,586	117,285
Navy SNF	200	1,949	5,430	39,214,523	7,843
Navy SNF–long	100	1,949	6,065	43,102,606	4,310
2 MCO/2 HLW	199	1,815	5,217	34,921,842	6,949
Totals	***16,631***				***551,012***

a. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
b. To convert millimeters to inches, multiply by 0.0394.
c. Surface area calculated as area of a right circular cylinder.
d. To convert square millimeters to square inches, multiply by 0.00155.
e. To convert square meters to square feet, multiply by 10.764.

Table I-21. Total exposed surface area of the Alloy-22 rails for all drip shields for the Module 1 inventory.

Component	Number of pieces	Average waste package emplacement length[a] (millimeters)[b]	Width[c] (millimeters)[d]	Thickness[c] (millimeters)[d]	Total surface area per average waste package[e] (square millimeters)[f]	Number of waste packages[c]	Total surface area for repository (square meters)[g]
Rail	2	5,076	115	10	1,370,520	16.631	22,793

a. Emplacement length estimate from DIRS 155393-CRWMS M&O (2000, Attachment V, p. V-2).
b. To convert meters to feet, multiply by 3.2808.
c. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
d. To convert millimeters to inches, multiply by 0.0394.
e. Surface area calculated as sum of areas of wetted surfaces (two rectangles) of angles running along the bottom of both sides of the drip shield.
f. To convert square millimeters to square inches, multiply by 0.00155.
g. To convert square meters to square feet, multiply by 10.764.

Table I-22. Total exposed surface area of the Alloy-22 outer layer of all waste packages for the Module 2 inventory.

Waste package type	Number[a]	Outer diameter[a] (millimeters[b])	Length[a] (millimeters[b])	Surface area[c] (square millimeters[d])	Total surface area (square meters[e])
21 PWR absorber plate	6,733	1,664	5,165	31,349,978	211,079
21 PWR control rods	114	1,664	5,165	31,349,978	3,574
12 PWR absorber plate	390	1,330	5,651	26,390,258	10,292
44 BWR absorber plate	4,408	1,674	5,165	31,564,675	139,137
24 BWR thick absorber plate	109	1,318	5,105	23,866,529	2,601
5 DHLW/DOE SNF	1,557	2,110	3,590	30,790,593	47,941
5 DHLW/DOE SNF–long	2,821	2,110	5,217	41,575,586	117,285
Navy SNF	200	1,949	5,430	39,214,523	7,843
Navy SNF–long	100	1,949	6,065	43,102,606	4,310
Navy–long (GTCC and SPAR)[f]	601	1,949	6,065	43,102,606	25,905
2 MCO/2 DHLW	199	1,815	5,217	34,921,842	6,949
Totals	***17,232***				***576,917***

a. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
b. To convert millimeters to inches, multiply by 0.0394.
c. Surface area calculated as area of a right circular cylinder.
d. To convert square millimeters to square inches, multiply by 0.00155.
e. To convert square meters to square feet, multiply by 10.764.
f. Navy SNF-long type waste packages used to represent disposal of Greater-Than-Class-C (GTCC) and Special-Performance-Assessment-Required (SPAR) waste.

Table I-23. Total exposed surface area of the Alloy-22 rails for all drip shields for the Module 2 inventory.

Component	Number of pieces	Average waste package emplacement length[a] (millimeters)[b]	Width[c] (millimeters)[d]	Thickness[c] (millimeters)[d]	Total surface area per average waste package[e] (square millimeters)[f]	Number of waste packages[c]	Total surface area for repository (square meters)[g]
Rail	2	5,076	115	10	1,370,520	17,232	23,617

a. Emplacement length estimate from DIRS 155393-CRWMS M&O (2000, Attachment V, p. V-2).
b. To convert meters to feet, multiply by 3.2808.
c. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
d. To convert millimeters to inches, multiply by 0.0394.
e. Surface area calculated as sum of areas of wetted surfaces (two rectangles) of angles running along the bottom of both sides of the drip shield.
f. To convert square millimeters to square inches, multiply by 0.00155.
g. To convert square meters to square feet, multiply by 10.764.

Table I-24. Total exposed surface area of the Alloy-22 components for all emplacement pallets under the Proposed Action, Module 1, and Module 2 inventories.

Emplacement pallet component[a]	Number of pieces[a]	Length[a] (millimeters)[b]	Width[a] (millimeters)	Number of sides[a]	Total surface area per pallet (square meters)[c]	Number of pallets[d]	Total surface area repository (square meters)[c]
Plate 1	2	1,845	552.4	1	4.077[e]		
Plate 2	2	922.5	614	2	2.266[f]		
Plate 3	2				2.219[g]		
Plate 4	4	552	462	2	2.040[h]		
Plate 5	4	552	80	2	0.353[i]		
Plate 6	4	1,266.7	603.2	2	6.113[j]		
Plate 7	4	152.4	79.9	2	0.049[k]		
Plate 8	4	152.4	552.4	1	0.337[l]		
Totals for Proposed Action					***17.45***	***11,301***	***197,240***
Totals for Inventory Module 1					***17.45***	***16,631***	***290,266***
Totals for Inventory Module 2					***17.45***	***17,232***	***300,756***

a. Emplacement pallet details from sketches SK-0189 Rev 0 and SK-0144 Rev 1, DIRS 150558-CRWMS M&O (2000).
b. To convert millimeters to inches, multiply by 0.0394.
c. To convert square meters to square feet, multiply by 10.764.
d. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
e. Calculated for one wetted rectangular side.
f. Calculated for both wetted rectangular sides.
g. Surface area equal to that of Plate 2 less area covered by 5.1-centimeter (2.0-inch) tube cross-sections.
h. Calculated assuming rectangular area covered by tubes is not wetted; note that while the inside and outside are covered by tubes the width dimension is correct for each side.
i. Calculated assuming rectangular wetted area.
j. Calculated assuming wetted area includes exposed edge thicknesses which are added to the length and width
k. Calculated based on triangular area.
l. Calculated assuming one wetted side only (because it is covered by the tube).

The sum of exposed total surface areas for waste packages, drip shield rails, and emplacement pallet components fabricated from Alloy-22 (from Tables I-18, I-19, and I-24) is 586,612 square meters (6,314,240 square feet) under the Proposed Action. For Inventory Module 1, the sum of exposed total surface areas (from Tables I-20, I-21, and I-24) is 864,072 square meters (9,300,794 square feet). For Inventory Module 2, the sum of exposed total surface areas (from Tables I-22, I-23, and I-24) is 901,290 square meters (9,701,400 square feet). This is the area of Alloy-22 subject to generalized corrosion under the assumptions outlined for this bounding impact estimate.

Tables I-25, I-26, and I-27 summarize the calculation of the total exposed surface areas for stainless steel 316NG used in the emplacement pallets for the Proposed Action, Module 1, and Module 2 inventories, respectively.

Table I-25. Total exposed surface area of the stainless-steel 316NG components for all emplacement pallets under the Proposed Action inventory.

Emplacement pallet tubes	Number of pieces[a]	Length[a] (millimeters[b])	Width[a] (millimeters)	Number of sides[a]	Total surface area per average waste package[c] (square meters[d])	Number of waste packages[e,f]	Total surface area repository (square meters)
Long pallets	4	4,147	609.6	2	18.877[f]	9,709	183,278
Short pallets	4	2,500	609.6	2	10.845[g]	1,592	17,265
Totals						***11,301***	***200,543***

a. Emplacement pallet details from sketches SK-0189 Rev 0 and SK-0144 Rev 1 (DIRS 150558-CRWMS M&O 2000).
b. To convert millimeters to inches, multiply by 0.0394.
c. Calculated for area of all wetted rectangular sides.
d. To convert square meters to square feet, multiply by 10.764.
e. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
f. Only waste packages of type "5 DHLW/DOE SNF" are assumed to utilize short pallets.

Table I-26. Total exposed surface area of the stainless-steel 316NG components for all emplacement pallets for the Module 1 inventory.

Emplacement pallet tubes	Number of pieces[a]	Length[a] (millimeters[b])	Width[a] (millimeters)	Number of sides[a]	Total surface area per average waste package[c] (square meters[d])	Number of waste packages[e,f]	Total surface area repository (square meters)
Long pallets	4	4,147	609.6	2	18.877[f]	15,075	284,533
Short pallets	4	2,500	609.6	2	10.845[g]	1,557	16,886
Totals						***16,632***	***301,419***

a. Emplacement pallet details from sketches SK-0189 Rev 0 and SK-0144 Rev 1 (DIRS 150558-CRWMS M&O 2000).
b. To convert millimeters to inches, multiply by 0.0394.
c. Calculated for area of all wetted rectangular sides.
d. To convert square meters to square feet, multiply by 10.764.
e. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
f. Only waste packages of type "5 DHLW/DOE SNF" are assumed to utilize short pallets.

Table I-27. Total exposed surface area of the stainless-steel 316NG components for all emplacement pallets for the Module 2 inventory.

Emplacement pallet tubes	Number of pieces[a]	Length[a] (millimeters[b])	Width[a] (millimeters)	Number of sides[a]	Total surface area per average waste package[c] (square meters[d])	Number of waste packages[e,f]	Total surface area repository (square meters)
Long pallets	4	4,147	609.6	2	18.877[f]	15,675	295,899
Short pallets	4	2,500	609.6	2	10.845[g]	1,557	16,886
Totals						***17,232***	***312,785***

a. Emplacement pallet details from sketches SK-0189 Rev 0 and SK-0144 Rev 1 (DIRS 150558-CRWMS M&O 2000).
b. To convert millimeters to inches, multiply by 0.0394.
c. Calculated for area of all wetted rectangular sides.
d. To convert square meters to square feet, multiply by 10.764.
e. Waste package data from DIRS 150558-CRWMS M&O (2000, all).
f. Only waste packages of type "5 DHLW/DOE SNF" are assumed to utilize short pallets.

I.6.2.3 General Corrosion Rates

The general corrosion rate for Alloy-22 has been measured in laboratory experiments. The corrosion rate was input to the TSPA model as a cumulative distribution function. The 5th percentile is 0.000012 millimeter (0.0000004 inch) per year, the median value is 0.000045 millimeter (0.0000017 inch) per year, and the 95th-percentile of the distribution is 0.00008 millimeter (0.000003 inch) per year (DIRS 152542-CRWMS M&O 2000, Figure 1, p. 11). For purposes of this bounding calculation, the median rate was chosen because the calculation is concerned with the average rate of corrosion over a large number of waste packages, drip shield rails, and emplacement pallets. Hence, the median rate is representative of repository conditions taken as a whole over the 10,000-year post-closure period.

The median general corrosion rate for stainless steel 316NG is 0.01 micron per year (0.0000394 inch per year) (DIRS 135968-CRWMS M&O 2000, Figure 3-15, p. 3-30).

I.6.2.4 Release Rates

The rate of release of waterborne chemically toxic materials was calculated as the product of the surface area exposed to general corrosion, the general corrosion rate, and the weight fraction of the alloy for the waterborne chemically toxic material of interest. Alloy-22 is comprised of among other elements, 22.5 percent (maximum) chromium, 14.5 percent (maximum) molybdenum, 57.2 percent nickel, and 0.35 percent vanadium (DIRS 104328-ASTM 1998, all). Stainless steel 316NG is assumed to be essentially the same as 316L, which is comprised, among other elements, of 17.0 percent chromium, 12 percent nickel, and 2.5 percent molybdenum with no vanadium (DIRS 102933-CRWMS M&O 1999, p. 13).

Tables I-28, I-29, and I-30 summarize the calculation of the bounding mass release rates for the Proposed Action, Module 1, and Module 2 inventories, respectively. The mass release rates for chromium, molybdenum, nickel, and vanadium are based on the surface exposure area of exposed repository components containing these elements, the general corrosion rates for those components, and the weight percent content of the individual elements.

Table I-28. Bounding mass release rates (grams per year)[a] from Alloy-22 and stainless-steel 316NG components from general corrosion for the Proposed Action.

Alloy	Total exposed surface area in repository (square meters)[b]	General corrosion rate (meters per year)[c]	Alloy release volume (cubic meter per year)[d]	Alloy density (grams per cubic meter)[e]	Bounding mass release rate (grams per year)[a]				
					Alloy	Chromium	Molybdenum	Nickel	Vanadium
Alloy-22	586,612	4.5×10^{-8}	0.0264	8,690,000	229,395	51,614	33,262	131,099	803
316NG	200,543	1.0×10^{-8}	0.00201	7,980,000	16,003	2,721	400	1,920	0
Totals						***54,334***	***33,662***	***133,019***	***803***

a. To convert grams to ounces, multiply by 0.035273.
b. To convert square meters to square feet, multiply by 10.764.
c. To convert meters to feet, multiply by 3.2468.
d. To convert cubic meters to cubic feet, multiply by 35.314.
e. To convert grams per cubic meter to ounces per cubic foot, multiply by 0.0010047.

Table I-29. Bounding mass release rates (grams per year)[a] from Alloy-22 and stainless-steel 316NG components from general corrosion for Module 1.

Alloy	Total exposed surface area in repository (square meters)[b]	General corrosion rate (meters per year)[c]	Alloy release volume (cubic meter per year)[d]	Alloy density (grams per cubic meter)[e]	Bounding mass release rate (grams per year)[a]				
					Alloy	Chromium	Molybdenum	Nickel	Vanadium
Alloy-22	864,072	4.5×10^{-8}	0.0389	8,690,000	337,895	76,026	48,995	193,107	1,183
316NG	312,785	1.0×10^{-8}	0.0030	7,980,000	24,055	4,089	601	2,887	0
Totals						***80,116***	***49,596***	***195,994***	***1,183***

a. To convert grams to ounces, multiply by 0.035273.
b. To convert square meters to square feet, multiply by 10.764.
c. To convert meters to feet, multiply by 3.2468.
d. To convert cubic meters to cubic feet, multiply by 35.314.
e. To convert grams per cubic meter to ounces per cubic foot, multiply by 0.0010047.

I.6.2.5 Summary of Bounding Impacts

The bounding maximum concentration is based on the general corrosion rate of the source materials and the representative volume for dilution prescribed in the final Environmental Protection Agency regulation 40 CFR Part 197. Diluting the bounding release rates presented in Section I.6.2.4 for chromium, molybdenum, nickel, and vanadium in the prescribed representative volume of water (3.7 million cubic meters, or exactly 3,000 acre-feet per year) used for calculation of groundwater protection impacts for

Table I-30. Bounding mass release rates (grams per year)[a] from Alloy-22 and stainless-steel 316NG components from general corrosion for Module 2.

Alloy	Total exposed surface area in reposritoy (square meters)[b]	General corrosion rate (meters per year)[c]	Alloy release volume (cubic meter per year)[d]	Alloy density (grams per cubic meter)[e]	Bounding mass release rate (grams per year)[a]				
					Alloy	Chromium	Molybdenum	Nickel	Vanadium
Alloy-22	901,290	4.5×10^{-8}	0.0406	8,690,000	352,450	79,301	51,105	201,425	1,233
316NG	312,785	1.0×10^{-8}	0.0031	7,980,000	24,960	4,243	624	2,995	0
Totals						***83,544***	***51,729***	***204,420***	***1,233***

a. To convert grams to ounces, multiply by 0.035273.
b. To convert square meters to square feet, multiply by 10.764.
c. To convert meters to feet, multiply by 3.2468.
d. To convert cubic meters to cubic feet, multiply by 35.314.
e. To convert grams per cubic meter to ounces per cubic foot, multiply by 0.0010047.

waterborne radioactive materials results in the bounding concentration in groundwater at exposure locations for these chemically toxic materials listed in Table I-31.

Table I-31. Bounding concentrations of waterborne chemical materials of concern compared to Maximum Contaminant Levels Goals (milligrams per liter).

Material	Maximum Contaminant Level Goal	Maximum bounding concentration		
		Proposed Action	Inventory Module 1	Inventory Module 2
Chromium (VI)	0.1[a]	0.015	0.022	0.023
Molybdenum	NA[b]	0.009	0.013	0.014
Nickel	NA	0.036	0.053	0.055
Vanadium	NA	0.00022	0.00032	0.00033

a. 40 CFR 141.51.
b. NA = not available.

There are two measures for comparing human health effects for chromium. When the Environmental Protection Agency established its Maximum Contaminant Level Goals, it considered safe levels of contaminants in drinking water and the ability to achieve these levels with the best available technology. The Maximum Contaminant Level Goal for chromium is 0.1 milligram per liter (40 CFR 141.51). The bounding concentrations for the Proposed Action and for Inventory Modules 1 and 2 (Table I-31) are well below the Maximum Contaminant Level Goal for chromium. The other measure for comparison is the Oral Reference Dose for chromium, which is 0.005 milligram per kilogram of body mass per day (DIRS 148224-EPA 1999, all). The reference dose factor represents a level of intake that has no adverse effect on humans. It can be converted to a threshold concentration level for drinking water. The conversion yields essentially the same concentration for the reference dose factor as the Maximum Contaminant Level Goal.

No attempt can be made at present to express the bounding estimate of groundwater concentration of hexavalent chromium in terms of human health effects (for example, latent cancer fatalities). The carcinogenicity of hexavalent chromium by the oral route of exposure cannot be determined because of a lack of sufficient epidemiological or toxicological data (DIRS 148224-EPA 1999, all; DIRS 101825-EPA 1998, p. 48).

There is no Maximum Contaminant Level Goals for molybdenum, nickel, or vanadium. However, we can compare the intake based on the maximum bounding concentrations in Table I-31 to the Oral Reference Dose for each of these materials. The intakes by chemical, assuming water consumption of 2 liters (0.53 gallon) per day by a 70-kilogram (154-pound) person, are listed in Table I-32 along with the relevant Oral Reference Dose. The values in Table I-32 show that the intakes are well below the respective Oral Reference Doses for chromium, molybdenum, nickel, and vanadium for the Proposed Action, Inventory Modules 1, and Inventory Module 2.

Table I-32. Summary of intake of waterborne chemical materials of concern based on maximum bounding concentrations listed in Table I-31 compared to Oral Reference Doses.

Material	Oral Reference Dose	Intake[a]		
		Proposed Action	Inventory Module 1	Inventory Module 2
Chromium (VI)	0.005[b]	0.00042	0.00062	0.00065
Molybdenum	0.005[c]	0.00026	0.00038	0.00040
Nickel	0.02[d]	0.0010	0.0015	0.0016
Vanadium	0.007[e]	0.0000062	0.0000091	0.000010

a. Assuming daily intake of 2.0 liters (0.53 gallon) per day by a 70-kilogram (154-pound) individual.
b. DIRS 148224-EPA 1999, all.
c. DIRS 148228-EPA 1999, all.
d. DIRS 148229-EPA 1999, all.
e. DIRS 103705-EPA 1997, all.

Because the bounding concentration of chromium, molybdenum, nickel, and vanadium in groundwater is calculated to be below the Maximum Contaminant Level Goal or yield intakes well below the respective Oral Reference Doses, there is no further need to refine the calculation to account for physical processes that would limit mobilization of these materials or delay and dilute them during transport in the geosphere.

I.7 Atmospheric Radioactive Material Impacts

Following closure of the proposed Yucca Mountain Repository, there would be limited potential for releases to the atmosphere because the waste would be isolated far below the ground surface. Still, the rock is porous and does allow gas to flow, so the analysis must consider possible airborne releases. The only radionuclide that would have a relatively large inventory and a potential for gas transport is carbon-14. Iodine-129 can exist in a gas phase, but it is highly soluble and, therefore, would be more likely to dissolve in groundwater rather than migrate as a gas. Other gas-phase isotopes were eliminated in the screening analysis (Section I.3.3), usually because they have short half-lives and are not decay products of long-lived isotopes. A separate screening argument for radon-222 is provided in Section I.7.3. After carbon-14 escaped from the waste package, it could flow through the rock in the form of carbon dioxide. Atmospheric pathway models were used to estimate human health impacts to the local population in the 80-kilometer (50-mile) region surrounding the repository.

About 2 percent of the carbon-14 in commercial spent nuclear fuel exists as a gas in the space (or *gap*) between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92). The average carbon-14 inventory in a commercial spent nuclear fuel waste package is approximately 1.37 grams (0.048 ounce) (6.11 curies) (see Table I-5), so the analysis used a gas-phase inventory of 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package to calculate impacts from the atmospheric release pathway. The waterborne radioactive materials analysis described in Chapter 5, Section 5.4 included the entire inventory of the carbon-14 in the repository in the groundwater release models. Thus, the groundwater-based impacts would be overestimated slightly (by 2 percent) by this modeling approach.

Carbon is the second-most abundant element (by mass) in the human body, constituting 23 percent of Reference Man (DIRS 101074-ICRP 1975, p. 327). Ninety-nine percent of the carbon comes from food ingestion (DIRS 148066-Killough and Rohwer 1978, p. 141). Daily carbon intakes are approximately 300 grams (0.7 pound) and losses include 270 grams (0.6 pound) exhaled, 7 grams (0.02 pound) in feces, and 5 grams (0.01 pound) in urine (DIRS 101074-ICRP 1975, p. 377).

Carbon-14 dosimetry can be performed assuming specific-activity equivalence. The primary human intake pathway of carbon is food ingestion. The carbon-14 in food results from photosynthetic processing of atmospheric carbon dioxide, whether the food is the plant itself or an animal that feeds on

Table I-32. Summary of intake of waterborne chemical materials of concern based on maximum bounding concentrations listed in Table I-31 compared to Oral Reference Doses.

Material	Oral Reference Dose	Intake[a]		
		Proposed Action	Inventory Module 1	Inventory Module 2
Chromium (VI)	0.005[b]	0.00042	0.00062	0.00065
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Nickel	0.02[d]	0.0010	0.0015	0.0016
Vanadium	0.007[e]	0.0000062	0.0000091	0.000010

a. Assuming daily intake of 2.0 liters (0.53 gallon) per day by a 70-kilogram (154-pound) individual.
b. DIRS 148224-EPA 1999, all.
c. DIRS 148228-EPA 1999, all.
d. DIRS 148229-EPA 1999, all.
e. DIRS 103705-EPA 1997, all.

Because the bounding concentration of chromium, molybdenum, nickel, and vanadium in groundwater is calculated to be below the Maximum Contaminant Level Goal or yield intakes well below the respective Oral Reference Doses, there is no further need to refine the calculation to account for physical processes that would limit mobilization of these materials or delay and dilute them during transport in the geosphere.

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About 2 percent of the carbon-14 in commercial spent nuclear fuel exists as a gas in the space (or *gap*) between the fuel and the cladding around the fuel (DIRS 103446-Oversby 1987, p. 92). The average carbon-14 inventory in a commercial spent nuclear fuel waste package is approximately 1.37 grams (0.048 ounce) (6.11 curies) (see Table I-5), so the analysis used a gas-phase inventory of 0.122 curie of carbon-14 per commercial spent nuclear fuel waste package to calculate impacts from the atmospheric release pathway. The waterborne radioactive materials analysis described in Chapter 5, Section 5.4 included the entire inventory of the carbon-14 in the repository in the groundwater release models. Thus, the groundwater-based impacts would be overestimated slightly (by 2 percent) by this modeling approach.

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Carbon-14 dosimetry can be performed assuming specific-activity equivalence. The primary human intake pathway of carbon is food ingestion. The carbon-14 in food results from photosynthetic processing of atmospheric carbon dioxide, whether the food is the plant itself or an animal that feeds on the plant. Biotic systems, in general, do not differentiate between carbon isotopes. Therefore, the carbon-14 activity concentration in the atmosphere will be equivalent to the carbon-14 activity concentration in the plant, which in turn will result in an equivalent carbon-14 specific activity in human tissues.

I.7.1 CARBON-14 RELEASES TO THE ATMOSPHERE

The calculation of regional radiological doses requires estimation of the annual release rate of carbon-14. The analysis based the carbon-14 release rate on the estimated timeline of container failures for the higher-temperature repository operating mode, using the time-dependent mean value of the number of failed waste packages. The expected number of commercial spent nuclear fuel waste package failures in 100-year intervals was used to estimate the carbon-14 release rate after repository closure. The estimated amount of material released from each package as a function of time was reduced to account for radiological decay.

As for the waterborne radioactive material releases described in Chapter 5, Section 5.4, credit was taken for the intact zirconium-alloy cladding (on approximately 99 percent by volume of the commercial spent nuclear fuel at emplacement) delaying the release of gas-phase carbon-14. The remaining 1 percent by volume of the commercial spent nuclear fuel either would have stainless-steel cladding (which degrades much more quickly than zirconium alloy) or would already have failed in the reactor. The cladding failure submodel of the TSPA model also estimates the time of the first perforation through the cladding. Because carbon-14 in gas form as carbon dioxide can migrate through small holes, the time of first perforation was used as the time of release from the carbon-14 from the failed fuel element. A plot of the fraction of the cladding that has been perforated as a function of time after repository closure is shown in Figure I-27.

The amount (in curies) of carbon-14 that would be available for transport, A_T, from a waste package at the time it fails is calculated as:

$$A_T = D_F \times F_{FC} \times 0.122 \text{ curies per package}$$

where:

D_F = Time-dependent factor that accounts for radioactive decay (unitless)

F_{FC} = Fraction of perforated cladding (unitless)

The analysis technique calculated the above quantity on a time interval of every 100 years. At each time interval, the amount of carbon-14, B_T, available for transport due to further cladding perforations in waste packages that failed previously was also calculated. This amount was calculated as follows:

$$B_T = D_F \times DF_{FC} \times N_{PF} \times 0.122 \text{ curies per package}$$

where:

DF_{FC} = Fraction of cladding that was perforated in the 100-year time interval (unitless)

N_{PF} = Number of waste packages that had failed prior to the current 100-year time interval (unitless)

Rather than conducting a detailed gas-flow model of the mountain, the analysis assumed that the carbon-14 from the failed waste package would be released to the ground surface uniformly over a

100-year interval. Thus, the release rate (curies per year) to the ground surface, G_S, for a time interval was calculated as follows:

$$G_S = (N_{CI} \times A_T + B_T) / 100$$

where:

N_{CI} = Number of waste packages that failed in the current 100-year time interval (unitless)

Figure I-28 shows the estimated release rate of carbon-14 from the repository for 80,000 years after repository closure, assuming that the commercial spent nuclear fuel with perforated cladding had released its gas-phase carbon-14 prior to being placed in a waste package. The results in Figure I-28 are based on the Proposed Action inventory. Each symbol in the figure represents the carbon-14 release rate to the ground surface for a period of 100 years. The general downward slope of the symbols is due to radioactive decay (carbon-14 has a half-life of 5,730 years). The symbols indicating near-zero releases (curies per year) indicate that no waste packages failed during some 100-year periods, and the fraction of perforated cladding changed only a small amount. Using this expected-value representation of waste package lifetime, only 1 of 7,860 commercial spent nuclear fuel waste packages would have failed during the first 10,000 years after repository closure. See Section I.2.4 for a description of early waste package failure mechanisms. The second waste package would fail at about 53,000 years after repository closure. By 80,000 years after repository closure, 131 of the 7,860 commercial spent nuclear fuel waste packages would have failed. Using this expected-value representation of the time of first cladding perforation, about 2 percent of the cladding would be perforated in the first 10,000 years. Thus, all releases prior to 50,000 years on Figure I-28 come from a single waste package. The maximum release rate would occur about 1,700 years after repository closure. The estimated maximum release rate would be about 3.3 microcurie per year.

For Inventory Module 1, the number of idealized waste packages containing commercial spent nuclear fuel would increase from 7,860 to 11,754. Using the expected value curves for waste package failure, there would only be 1 waste package failure in the first 10,000 years for Inventory Module 1. Even though the modeled time of the waste package failure is 100 years earlier than for the Proposed Action inventory, the expected value for the fraction of cladding perforated is nearly identical for the two inventory modules during the first 10,000 years. Thus, the maximum release rate to the ground surface is the same and occurs at the same time for both inventory modules. Inventory Module 2 would not add any additional materials expected to contain gas-phase carbon-14, so it would have the same maximum release rate to the ground surface as the Proposed Action inventory.

I.7.2 ATMOSPHERE CONSEQUENCES TO THE LOCAL POPULATION

DOE used the GENII program (DIRS 100953-Napier et al. 1998, all) to model the atmospheric transport and human uptake of released carbon-14 for the 80-kilometer (50-mile) population radiological dose calculation. Radiological doses to the regional population near Yucca Mountain from carbon-14 releases were estimated using the population distribution described in Appendix G, Section G.2.1, which indicates approximately 76,000 people would live in the region surrounding Yucca Mountain in 2035. The population by distance and sector used in the calculations are listed in Table G-48. The computation also used current (1993 to 1996) annual average meteorology. The joint frequency data are listed in Table I-33.

A population radiological dose factor of 4.6×10^{-9} person-rem per microcurie per year of release was calculated using the GENII code. For a 3.3-microcurie-per-year maximum release rate, an 80-kilometer (50-mile) population radiological dose rate would be 1.5×10^{-8} person-rem per year. This radiological dose rate represents 7.5×10^{-12} latent cancer fatality in the regional population of 76,000 persons each

Table I-33. Meteorologic joint frequency data used for Yucca Mountain atmospheric releases (percent of time).[a]

Average wind speed (m/s)[b]	Atmospheric stability class	Direction (wind toward) S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.9	A	0.807	0.633	0.613	0.520	0.462	0.604	0.688	0.659	0.467	0.340	0.183	0.200	0.197	0.212	0.412	0.778
	B	0.279	0.479	0.392	0.325	0.372	0.540	1.243	2.279	1.484	0.499	0.290	0.192	0.105	0.070	0.087	0.305
	C	0.113	0.105	0.064	0.017	0.015	0.020	0.041	0.157	0.122	0.067	0.055	0.020	0.012	0.020	0.009	0.032
	D	0.003	0.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2.55	A	0.099	0.073	0.026	0.020	0.026	0.017	0.023	0.061	0.041	0.029	0.023	0.017	0.029	0.029	0.052	0.096
	B	0.058	0.044	0.038	0.026	0.032	0.061	0.125	0.377	0.360	0.070	0.049	0.015	0.009	0	0.009	0.017
	C	0.229	0.267	0.256	0.116	0.110	0.105	0.328	1.193	2.404	0.909	0.671	0.302	0.157	0.142	0.125	0.174
	D	0.105	0.049	0.038	0.003	0.003	0.003	0.006	0.035	0.444	0.290	0.206	0.055	0.035	0.049	0.087	0.099
	E	0.003	0.006	0	0.003	0	0	0.003	0.003	0.003	0.006	0.003	0.003	0.003	0.003	0	0.003
	F	0	0.003	0	0	0	0	0	0	0.003	0.003	0	0	0	0	0	0.003
4.35	A	0.096	0.096	0.041	0.015	0.012	0.009	0.015	0.023	0.058	0.044	0.026	0.023	0.029	0.020	0.020	0.070
	B	0.052	0.087	0.041	0.023	0.006	0.026	0.078	0.261	0.305	0.131	0.076	0.017	0.006	0.003	0.009	0.032
	C	0.142	0.241	0.168	0.070	0.029	0.076	0.131	0.740	1.638	0.308	0.290	0.119	0.049	0.041	0.038	0.102
	D	0.253	0.264	0.163	0.049	0.020	0.020	0.020	0.392	2.375	0.447	0.285	0.081	0.046	0.058	0.139	0.346
	E	0.006	0.017	0	0	0	0	0	0.003	0.006	0.020	0.015	0.006	0.003	0.003	0.012	0.020
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.95	A	1.568	0.642	0.215	0.038	0.035	0.009	0.023	0.026	0.081	0.142	0.261	0.163	0.209	0.314	0.343	0.819
	B	0.682	0.552	0.067	0.003	0.006	0.006	0.023	0.058	0.348	0.325	0.267	0.131	0.078	0.093	0.078	0.256
	C	0.993	0.560	0.105	0.012	0.009	0.078	0.090	0.244	0.984	0.526	0.337	0.192	0.067	0.076	0.073	0.189
	D	1.594	0.912	0.183	0.020	0.020	0.006	0.035	0.566	3.368	0.430	0.160	0.128	0.035	0.044	0.142	0.598
	E	0.735	0.366	0.067	0.012	0.006	0	0	0.386	2.515	0.192	0.038	0.015	0	0.015	0.064	0.804
	F	0.238	0.096	0.003	0	0.003	0	0	0.142	1.641	0.055	0.032	0	0.003	0.003	0.029	0.796
9.75	A	2.134	0.935	0.218	0.078	0.029	0.041	0.026	0.070	0.163	0.232	0.203	0.232	0.267	0.372	0.587	1.388
	B	0.865	0.627	0.081	0.009	0.003	0.017	0.020	0.046	0.319	0.267	0.154	0.131	0.070	0.052	0.113	0.302
	C	0.720	0.261	0.038	0.012	0.020	0.020	0.009	0.076	0.502	0.299	0.148	0.229	0.078	0.032	0.041	0.157
	D	0.415	0.212	0.020	0.003	0.003	0.003	0.003	0.046	0.627	0.154	0.044	0.032	0.029	0.009	0.026	0.145
	E	0.029	0.006	0	0	0.003	0	0	0	0.006	0.003	0.003	0	0	0.003	0	0.003
	F	0	0.003	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0.003
12.98	A	1.661	0.706	0.418	0.322	0.247	0.244	0.366	0.343	0.407	0.380	0.302	0.299	0.357	0.537	1.083	2.038
	B	0.836	0.668	0.253	0.107	0.157	0.116	0.264	0.499	0.674	0.404	0.270	0.171	0.122	0.096	0.232	0.950
	C	0.322	0.267	0.087	0.017	0.006	0.012	0.026	0.136	0.311	0.107	0.032	0.029	0.020	0.009	0.015	0.038
	D	0.006	0.006	0	0	0	0	0	0.003	0.012	0.003	0	0	0	0	0	0.003
	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

a. Source: Adapted from data in DIRS 102877-CRWMS M&O (1999, Appendix B, all).
b. m/s = meters per second; to convert meters per second to miles per hour, multiply by 2.237.

year at the maximum release rate. This annual population radiological dose rate corresponds to a lifetime radiological population dose of 1.1×10^{-6} rem (assuming a 70-year lifetime), which corresponds to 5.3×10^{-10} latent cancer fatality during the 70-year period of the maximum release.

The impacts were also calculated for a maximally exposed individual. Given the population data in Appendix G, Table G-48 and the joint frequency data in Table I-33, the maximally exposed individual would reside 24 kilometers (15 miles) south of the repository. An individual radiological dose factor of 5.6×10^{-14} rem per microcurie per year of release was calculated using the GENII code for this location. For a 3.3-microcurie-per-year maximum release rate, the individual maximum radiological dose rate would be 1.8×10^{-13} rem per year, corresponding to a 9.2×10^{-17} probability of a latent cancer fatality. The 70-year lifetime dose would be 1.3×10^{-11} rem, representing a 6.4×10^{-15} probability of a latent cancer fatality.

I.7.3 SCREENING ARGUMENT FOR RADON

The uranium placed in the repository would continuously produce radon as a decay product. The longest-lived radon isotope is radon-222, with a half-life of 4 days (DIRS 103178-Lide and Frederikse 1997, p. 4-24). The only potential transport and human exposure pathway for radon would be through the atmosphere because radon would not travel far enough in water to reach an individual before decaying.

A study performed by Y.S. Wu and others (DIRS 103690-Wu, Chen, and Bodvarsson 1995, all) at Lawrence Berkeley National Laboratory calculated gas and heat flow from the mountain due to steam formation and repository induced heating. This study calculated heat and mass fluxes for 57- and 114-kilowatt-per-acre emplacements. The study indicated maximum gas fluxes at the surface of about 2×10^{-7} kilogram per second per square meter at the Ghost Dance and Solitario Canyon faults and generally no more that 2×10^{-9} kilogram per second per square meter over the remainder of the surface.

The gas flux at the Ghost Dance fault was used to estimate a lower limit for the gas travel time after the waste packages began to fail. The travel times would be longer for a smaller thermal gradient and most waste packages are estimated to remain intact until long after the thermal gradient from the waste emplacement had declined to almost zero. However, this calculation still applies if a waste package failed during the period of highest thermal gradient.

A gas pore velocity, using the estimated gas flux for the Ghost Dance Fault, applicable for gas travel from the repository horizon to the surface, is calculated from the following equation:

$$Vp = Fg / (Da \times Rp)$$

where:

Fg = Gas flux (2×10^{-7} kilogram per second per meter squared)

Da = Density of air (approximately 1.2 kilogram per cubic meter at 20º Celsius) (DIRS 127163-Weast 1972, p. F-11)

Rp = Rock porosity (0.082, unitless) (DIRS 100033-Flint 1998, Table 7, p. 44)

Vp = Pore Velocity (meters per second) = 2.03×10^{-6}

Travel time from the repository horizon to the surface is calculated from the following equation:

$$T_t = Rd / (Vp \times 86400)$$

year at the maximum release rate. This annual population radiological dose rate corresponds to a lifetime radiological population dose of 1.1×10^{-6} rem (assuming a 70-year lifetime), which corresponds to 5.3×10^{-10} latent cancer fatality during the 70-year period of the maximum release.

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Rp = Rock porosity (0.082, unitless) (DIRS 100033-Flint 1998, Table 7, p. 44)

Vp = Pore Velocity (meters per second) = 2.03×10^{-6}

Travel time from the repository horizon to the surface is calculated from the following equation:

$$T_t = Rd / (Vp \times 86400)$$

where:

Rd	=	Depth to the repository (approximately 200 meters)
86400	=	Number of seconds per day
T_t	=	Gas travel time (days) = 1,140

Because the radioactive decay constant for radon-222 is 0.18145 (per day), radioactive decay would reduce the amount of radon-222 in the air by approximately 90 orders of magnitude in the time it took the air to travel from the repository horizon up through 200 meters (660 feet) of overlying rock. Therefore, no human effects are anticipated from the atmospheric release of radon-222 in the waste packages.

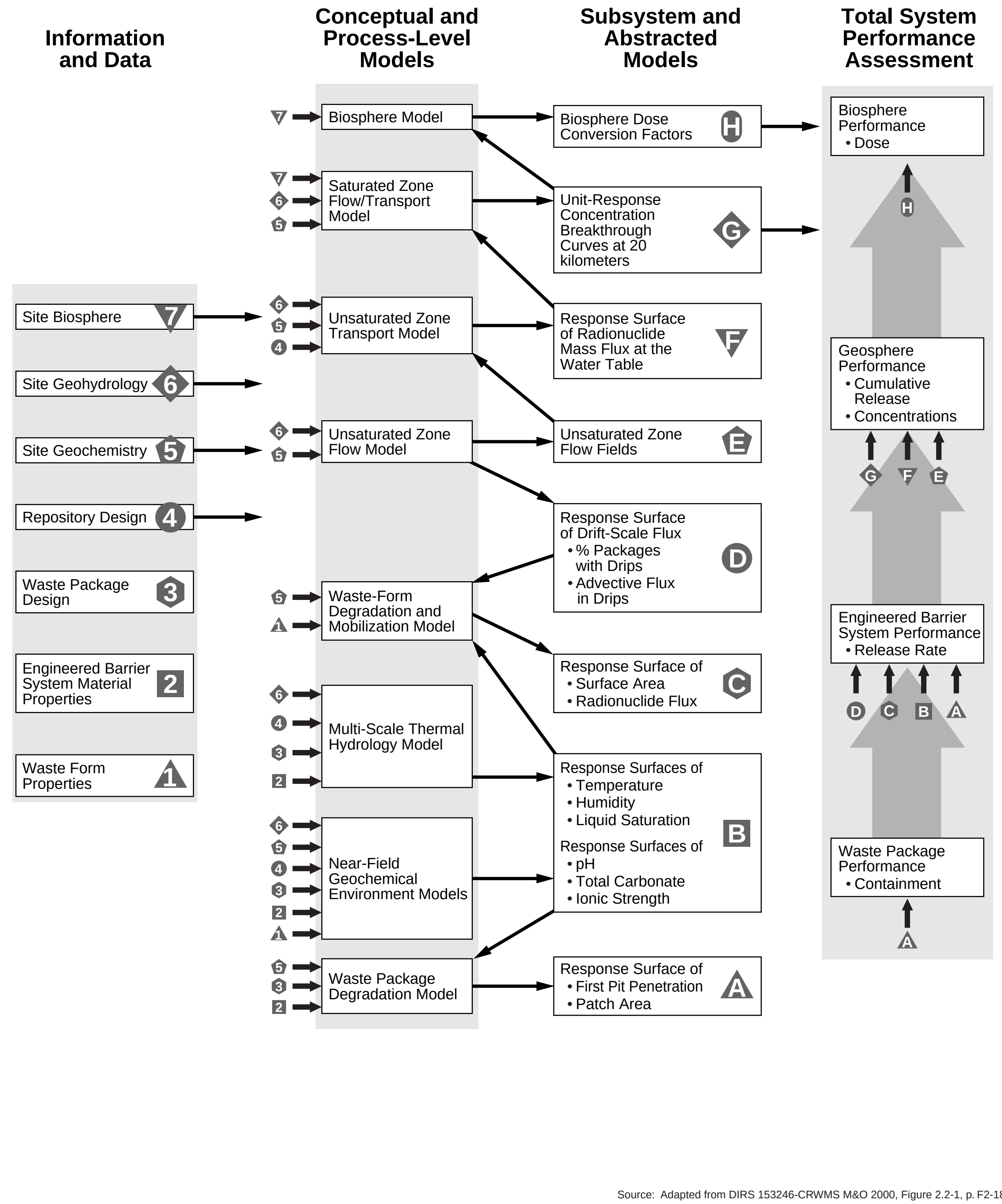


Figure I-1. TSPA model.

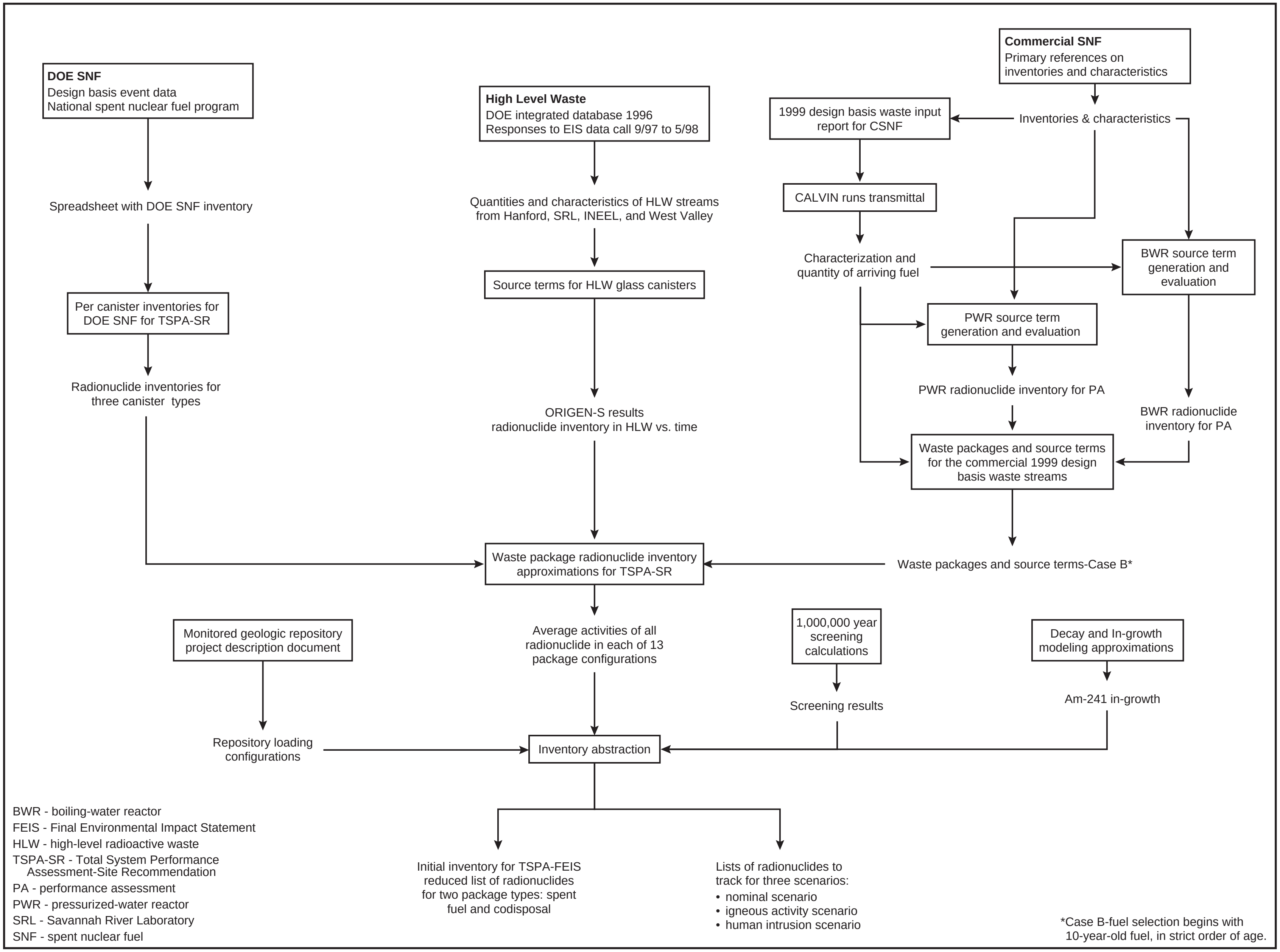


Figure I-2. Development of abstracted inventory for TSPA-FEIS.

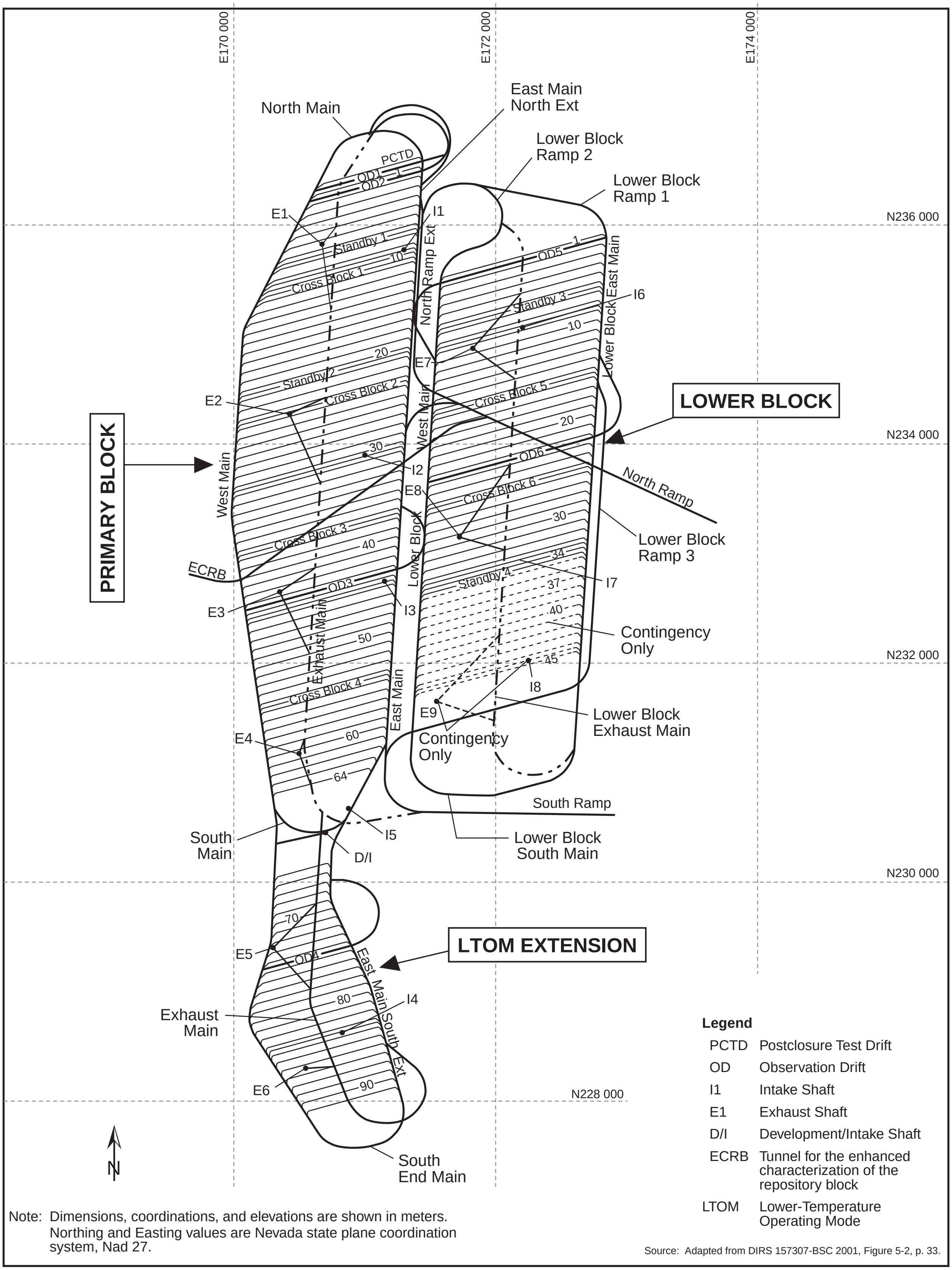
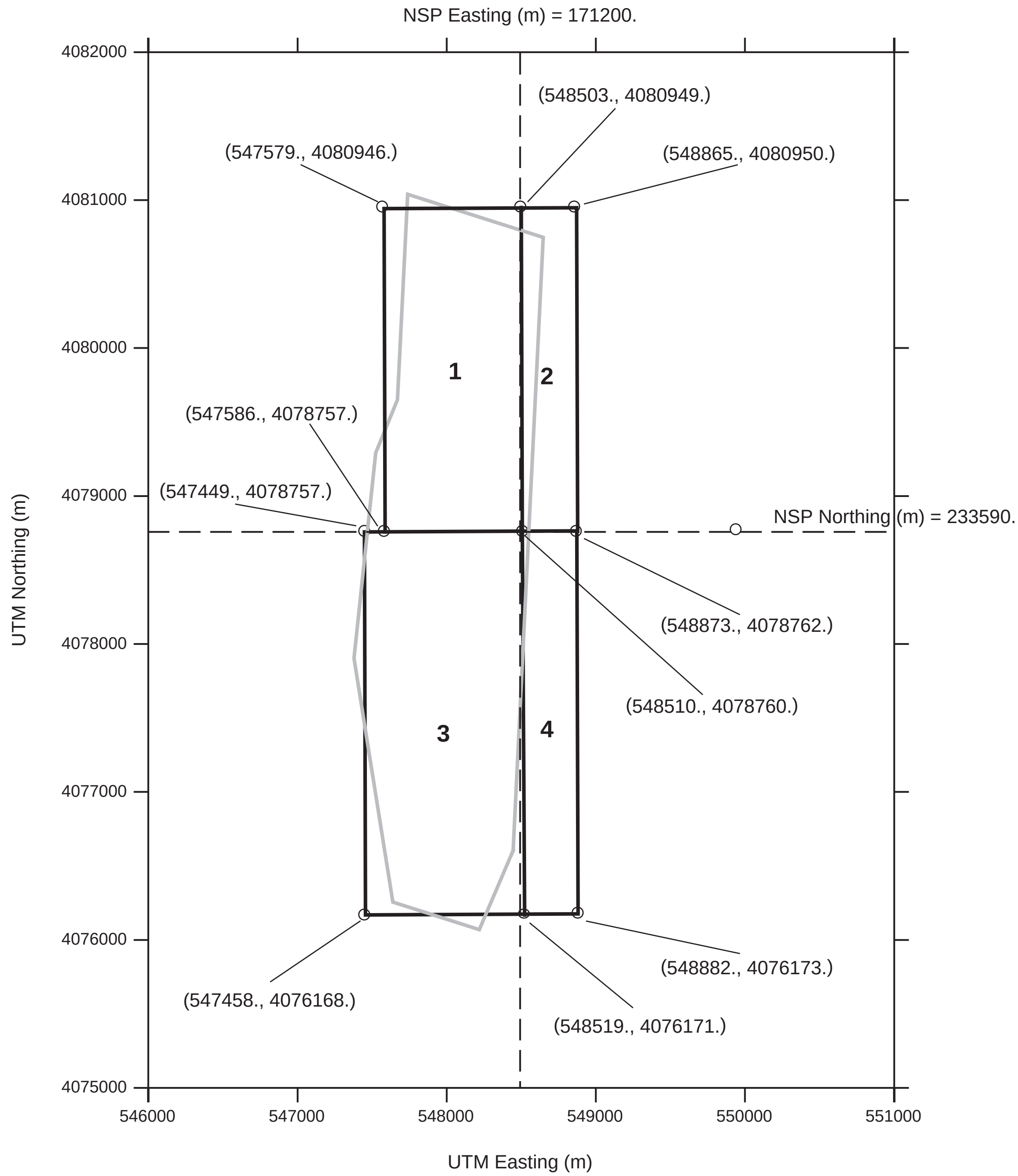


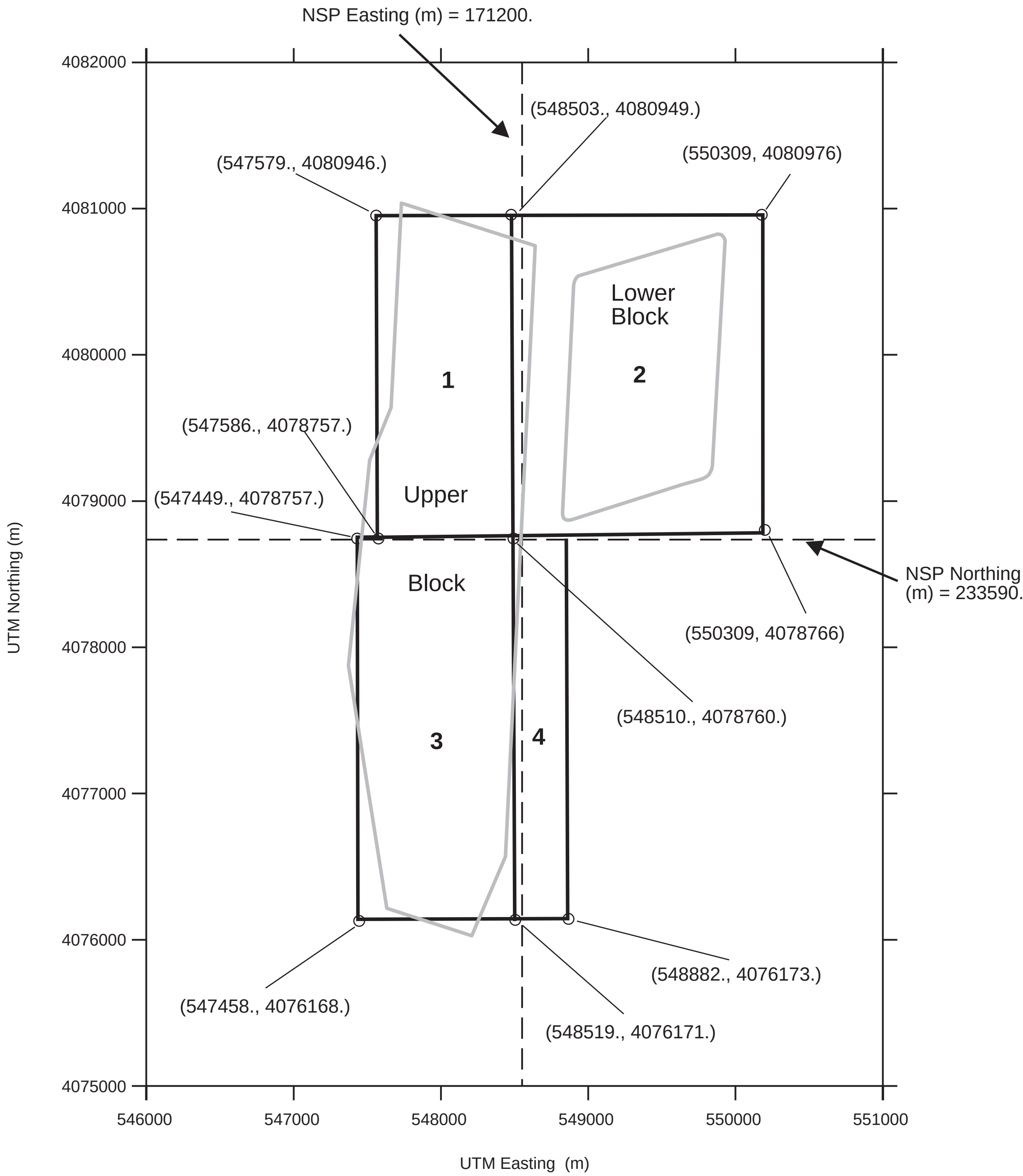
Figure I-3. Approximate configuration of the proposed Yucca Mountain Repository.



Note: Source regions are outlined with the solid black rectangles and numbered from 1 to 4. The coordinates of the vertices of the source region rectangles are given in Universal Transverse Mercator (UTM) coordinates (meters). The outline of the repository is shown by the gray lines. The dashed lines indicate the quadrants from which radionuclide arrivals from the unsaturated zone model are applied to the saturated zone source regions. Coordinates of the dashed lines are given in Nevada State Plan (NSP) coordinates (meters).

Source: Adapted from DIRS 157307-BSC 2001, Figure 5-3, p. 34.

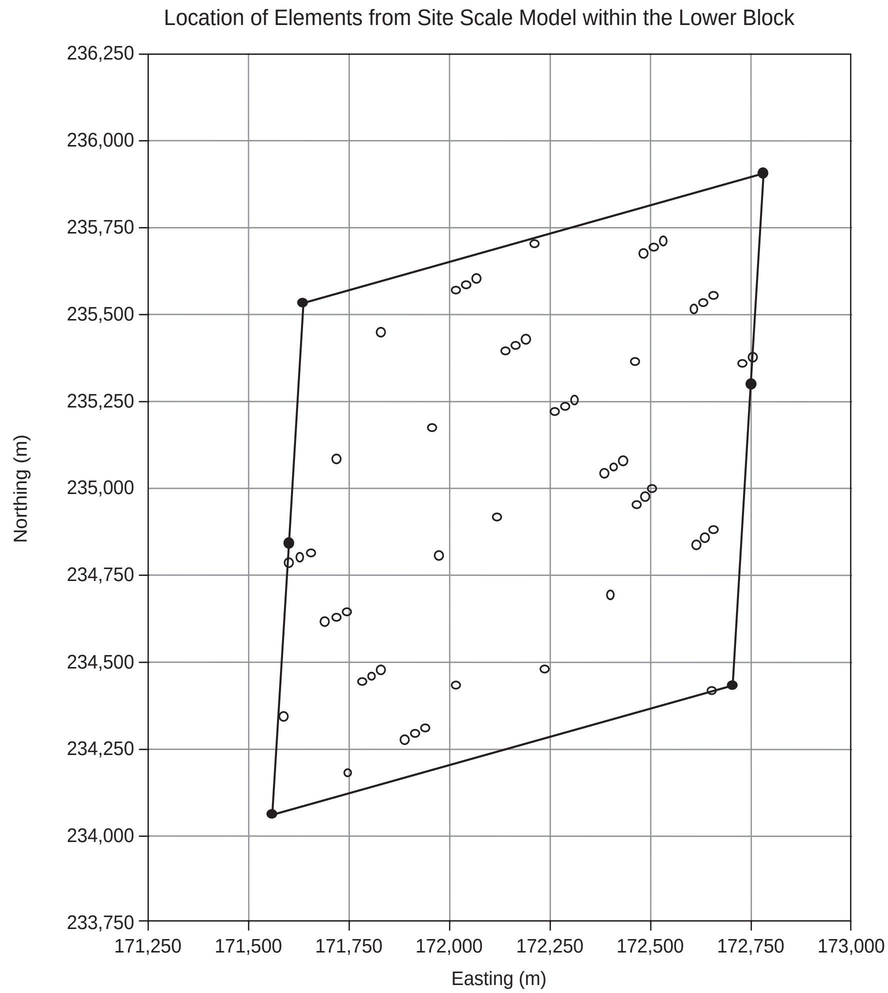
Figure I-4. The four saturated zone capture regions in relation to the primary repository block for the Proposed Action.



Note: Source regions are outlined with the solid black rectangles and numbered from 1 to 4. The coordinates of the vertices of the source region rectangles are given in Universal Transverse Mercator (UTM) coordinates (meters). The outline of the repository is shown by the gray lines. The dashed lines indicate the quadrants from which radionuclide arrivals from the unsaturated zone model are applied to the saturated zone source regions. Coordinates of the dashed lines are given in Nevada State Plan (NSP) coordinates (meters).

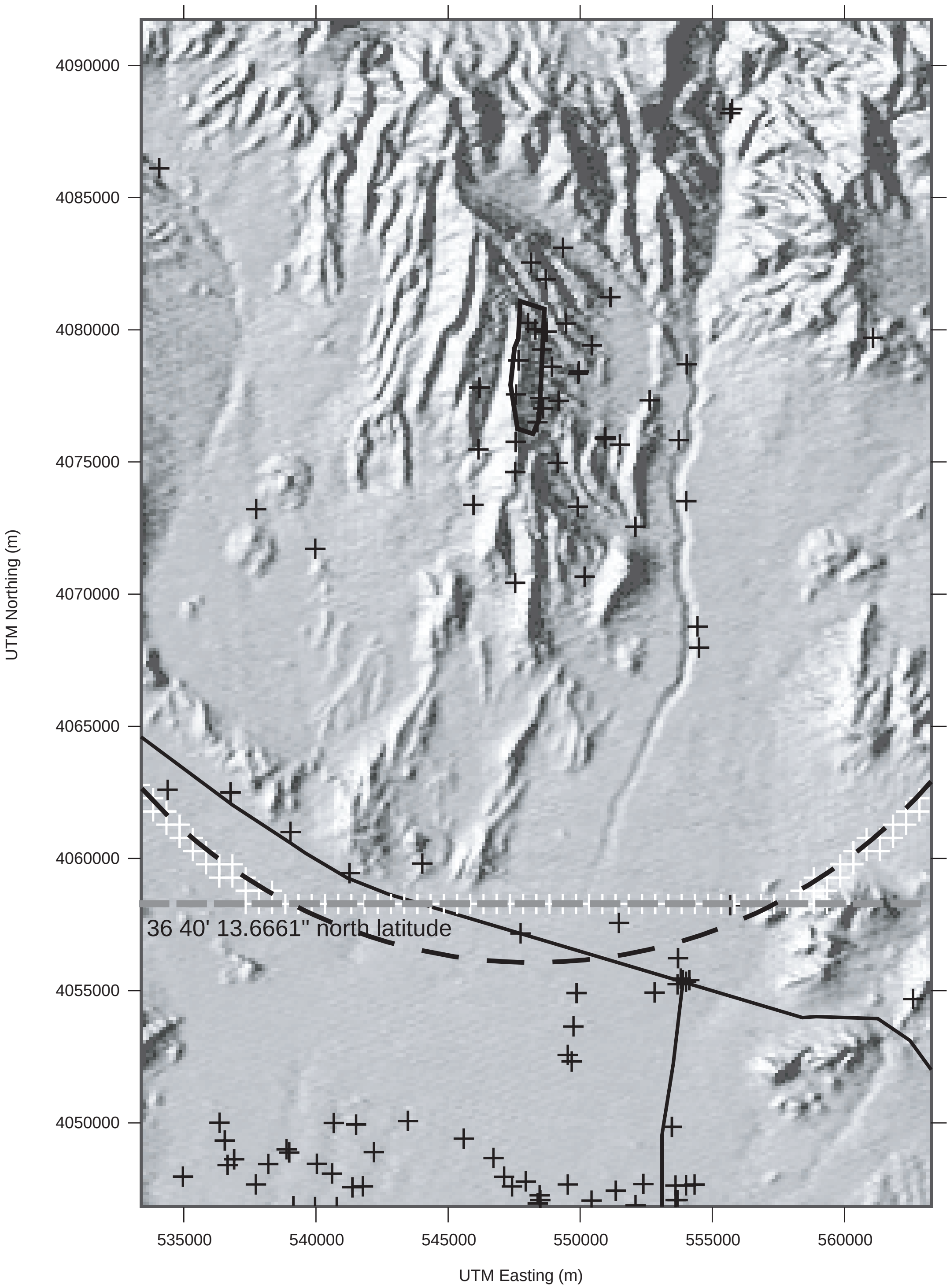
Source: Adapted from DIRS 157307-BSC 2001, Figure 5-4, p. I-35.

Figure I-5. The four saturated zone capture regions in relation to the primary and lower repository blocks for Inventory Modules 1 and 2.



Source: Adapted from DIRS 157307-BSC 2001, Figure 5-5, p. 36.

Figure I-6. Outline of the Lower Block showing the locations of the 51 particle-tracking nodes.



Note: The horizontal dashed line represents the southernmost boundary between the controlled area and accessible environment (36º 40' 13.6661" North latitude as per EPA 40 CFR Part 197). The semicircular dashed line represents the 20-kilometer (12-mile) fence used in the TSPA-SR model to evaluate compliance with the then-proposed Environmental Protection Agency and Nuclear Regulatory Commission regulations. The white crosses represent the saturated zone transport model grid cells at the intersection of the new southernmost boundary with the 20-kilometer fence used in TSPA-SR evaluations. The black crosses are well locations, and the solid black lines represent Highway 95 and Highway 373.

Source: Adapted from DIRS 157307-BSC 2001, Figure 5-6, p. 37.

Figure I-7. Southernmost boundary of the controlled area and the accessible environment.

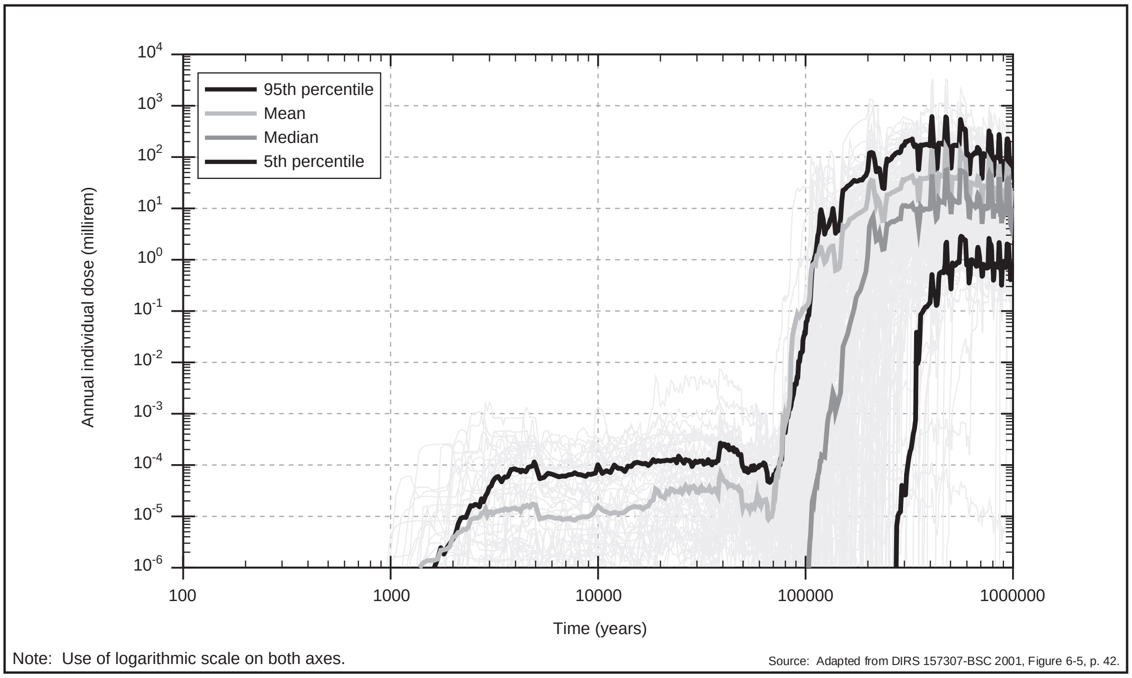


Figure I-12. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the higher-temperature operating mode for the Proposed Action inventory, nominal scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

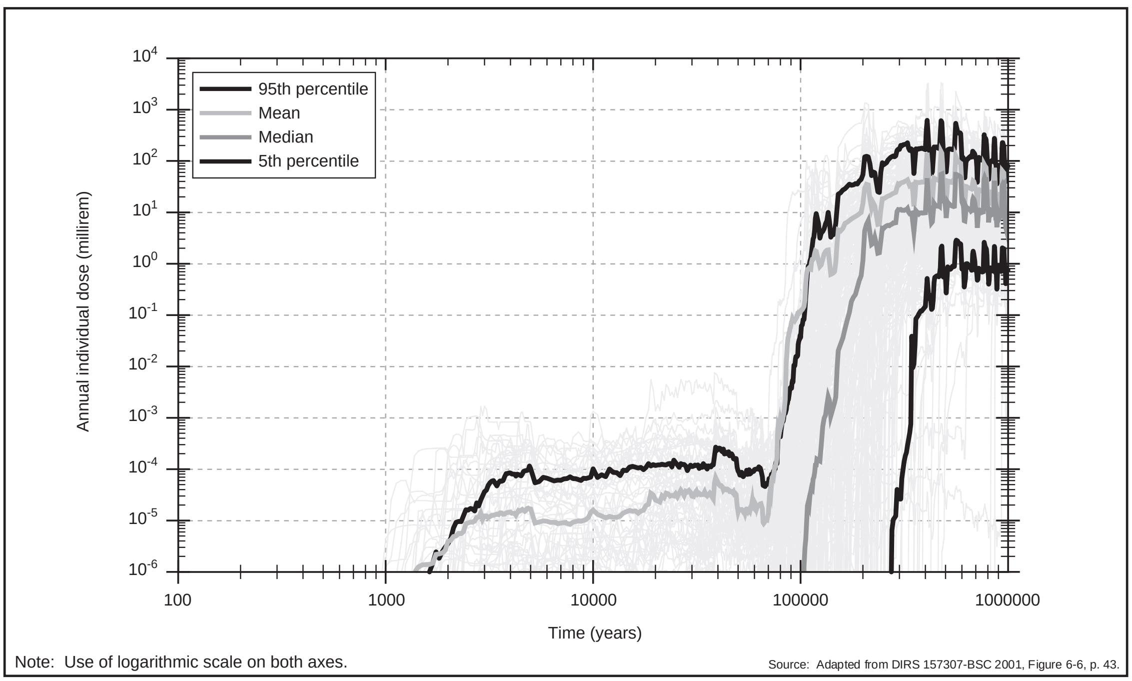


Figure I-13. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the lower-temperature operating mode for the Proposed Action inventory, nominal scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

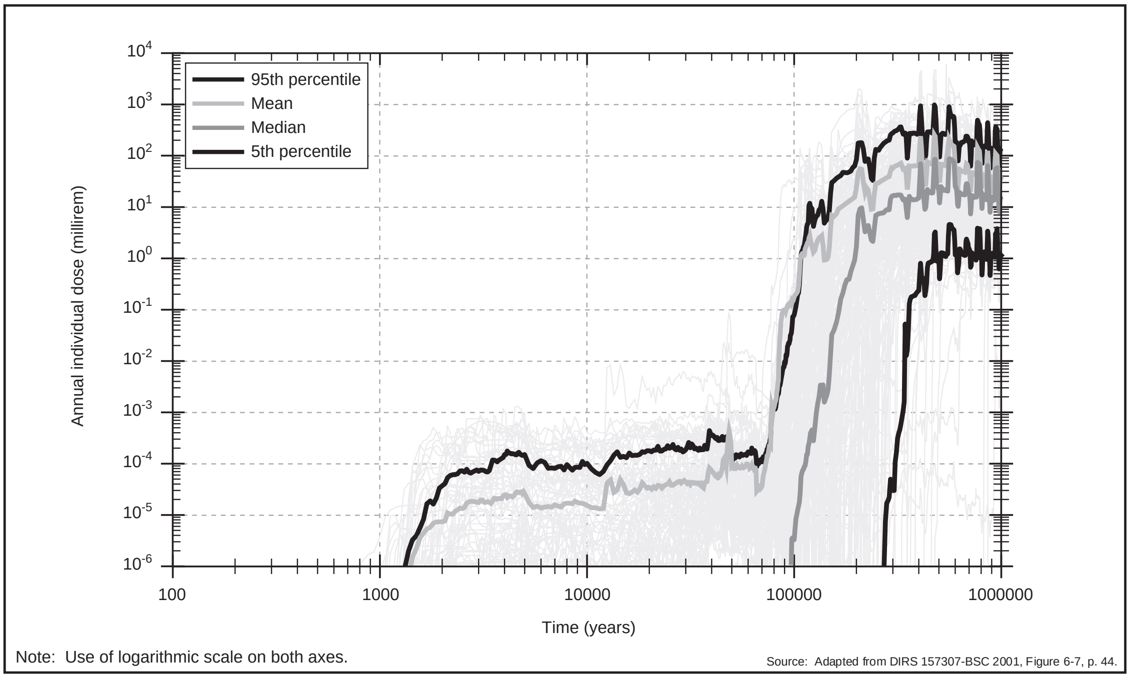


Figure I-14. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the higher-temperature operating mode for the Module 1 inventory, nominal scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

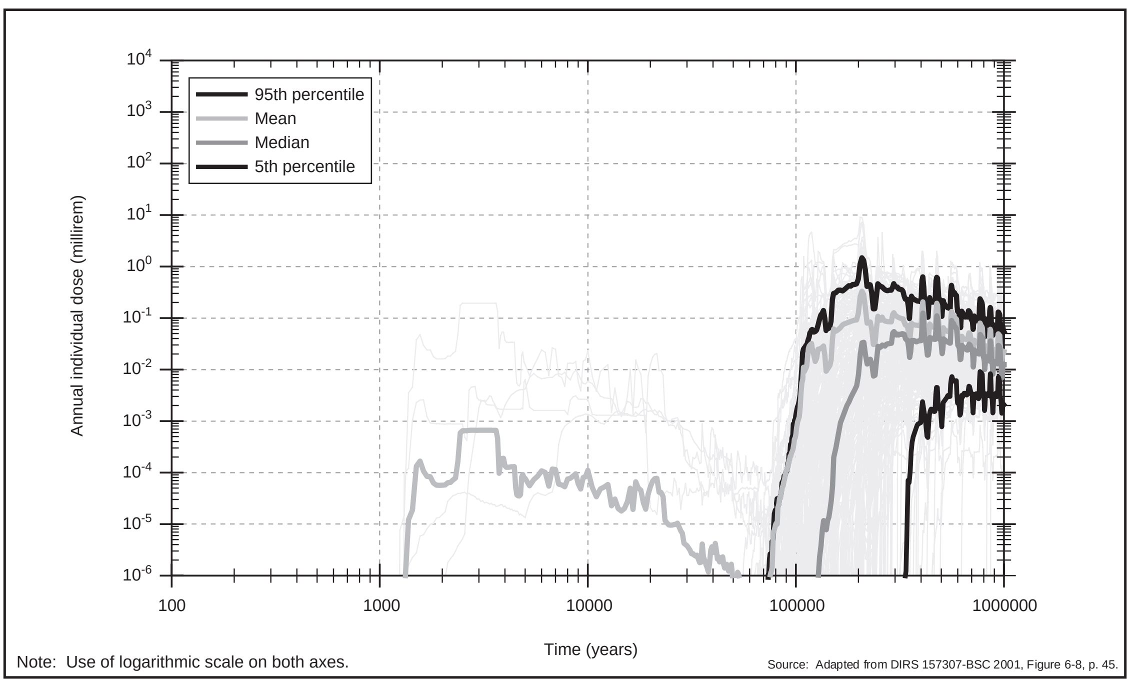


Figure I-15. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the higher-temperature operating mode for the Module 2 incremental inventory, nominal scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

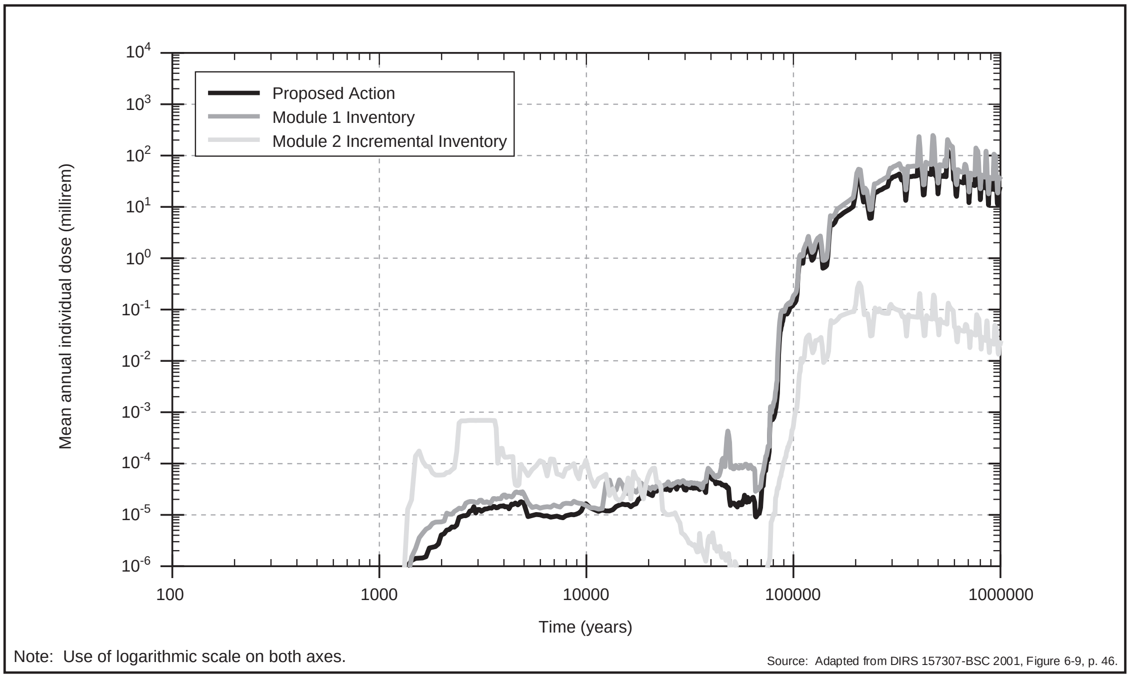


Figure I-16. Comparison plot of the mean total annual individual dose at the RMEI location for the higher-temperature operating mode for the Proposed Action, Module 1, and incremental Module 2 inventories, nominal scenario.

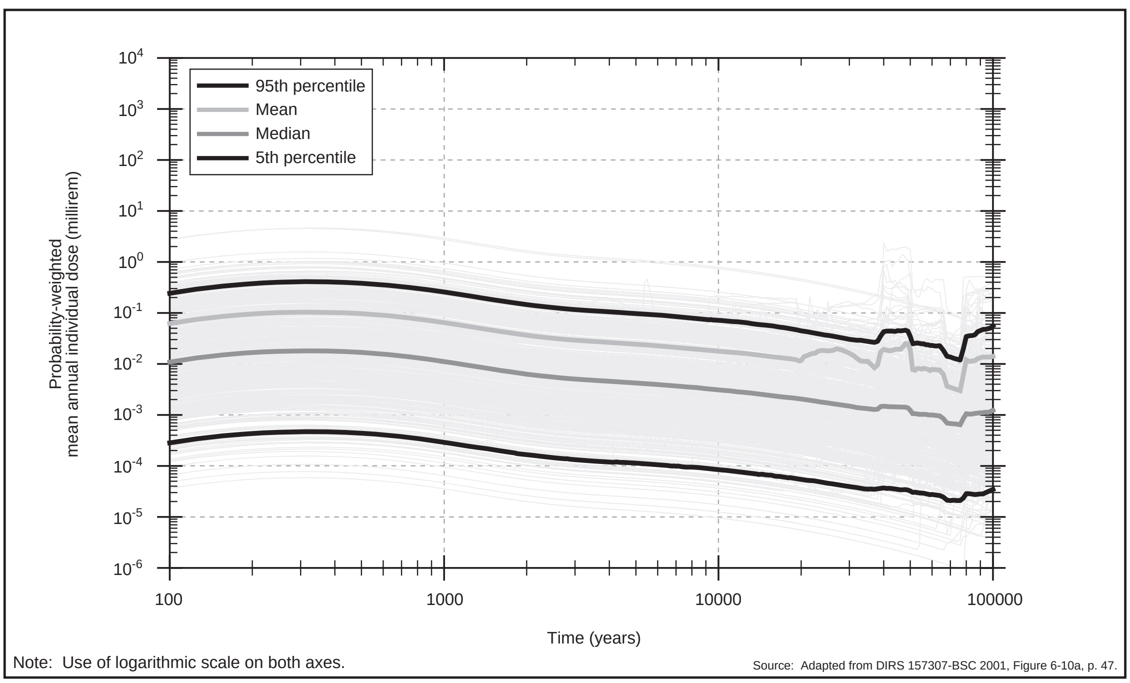


Figure I-17. Total annual individual dose at the RMEI location for 500 out of 5,000 probabilistic simulations of the higher-temperature operating mode for the Proposed Action inventory under the igneous activity scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of all 5,000 simulations.

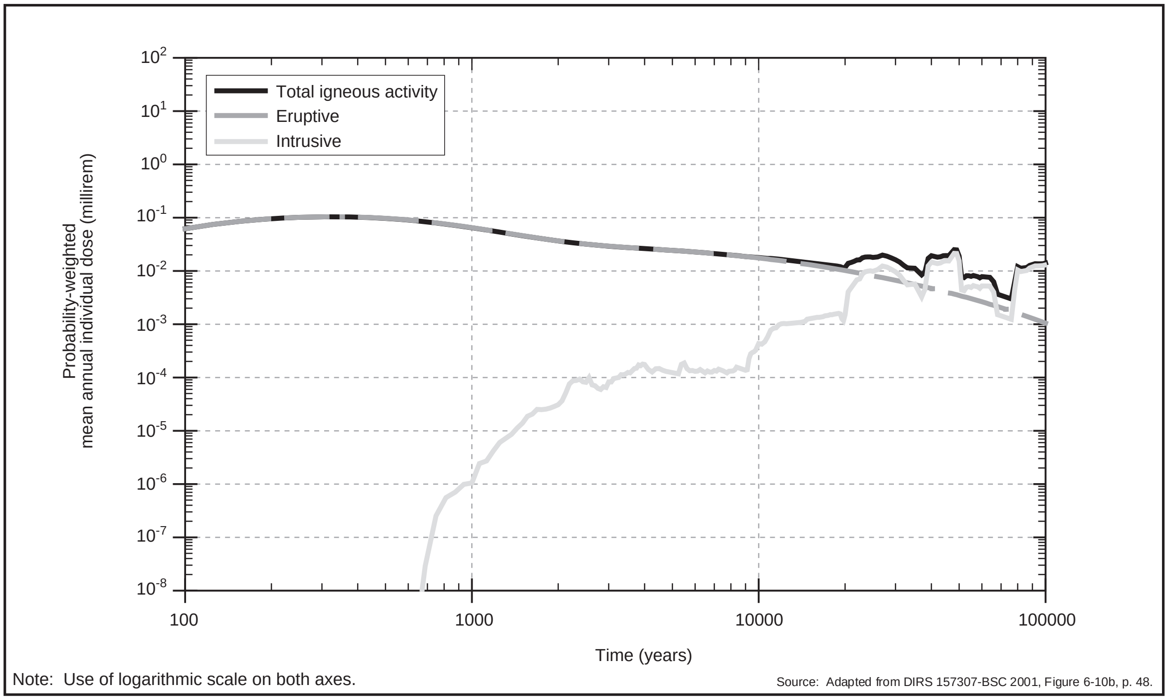


Figure I-18. Total mean individual receptor dose at the RMEI location for the higher-temperature operating mode for the Proposed Action inventory under the igneous activity scenario; the figure displays the mean results for both the eruptive and intrusive events and the sum of these events as "Total Igneous."

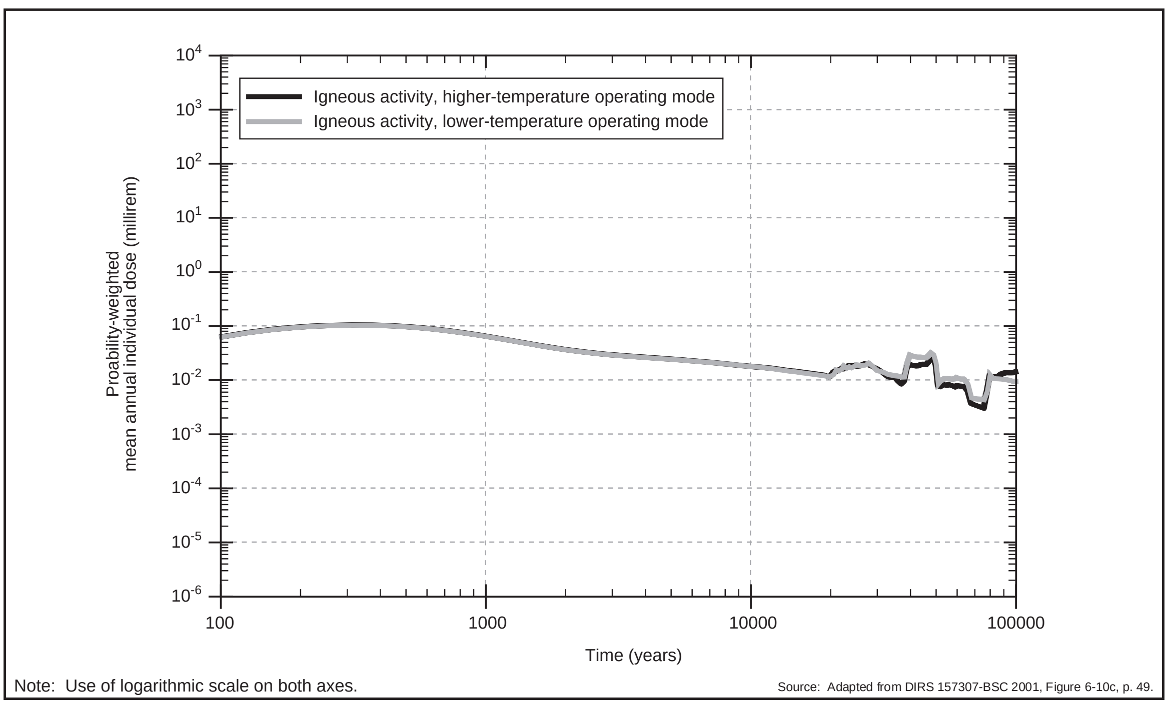


Figure I-19. Total mean annual individual dose at the RMEI location for the higher-temperature and lower-temperature operating modes for the Proposed Action inventory under the igneous activity scenario.

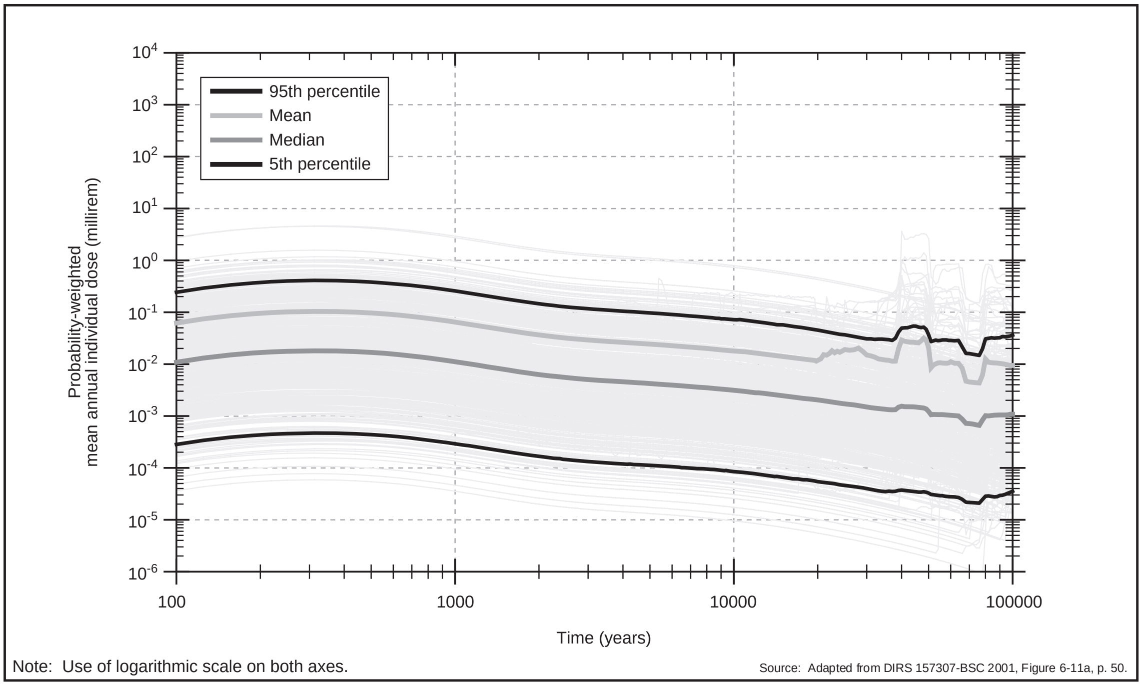


Figure I-20. Total annual individual dose at the RMEI location for 500 out of 5,000 probabilistic simulations of the lower-temperature operating mode for the Proposed Action inventory under the igneous activity scenario; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.

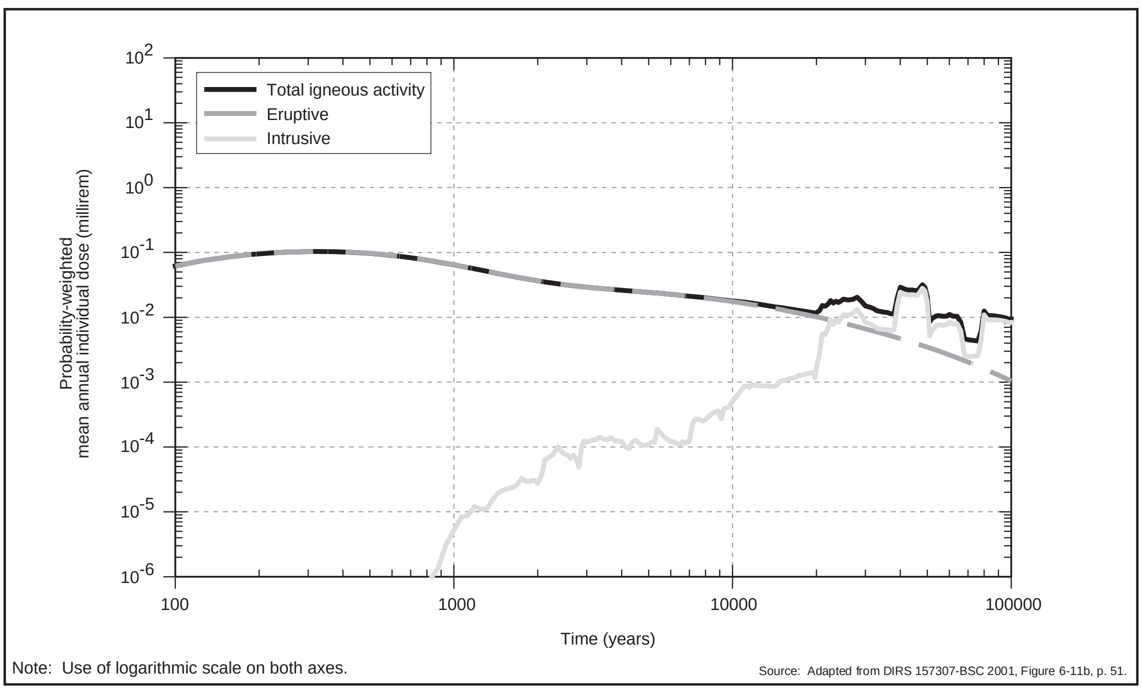
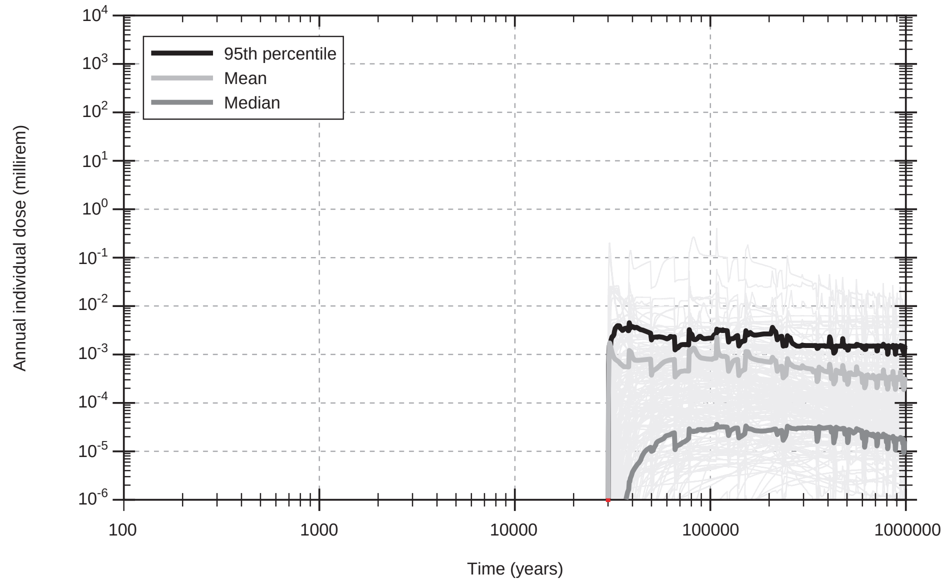


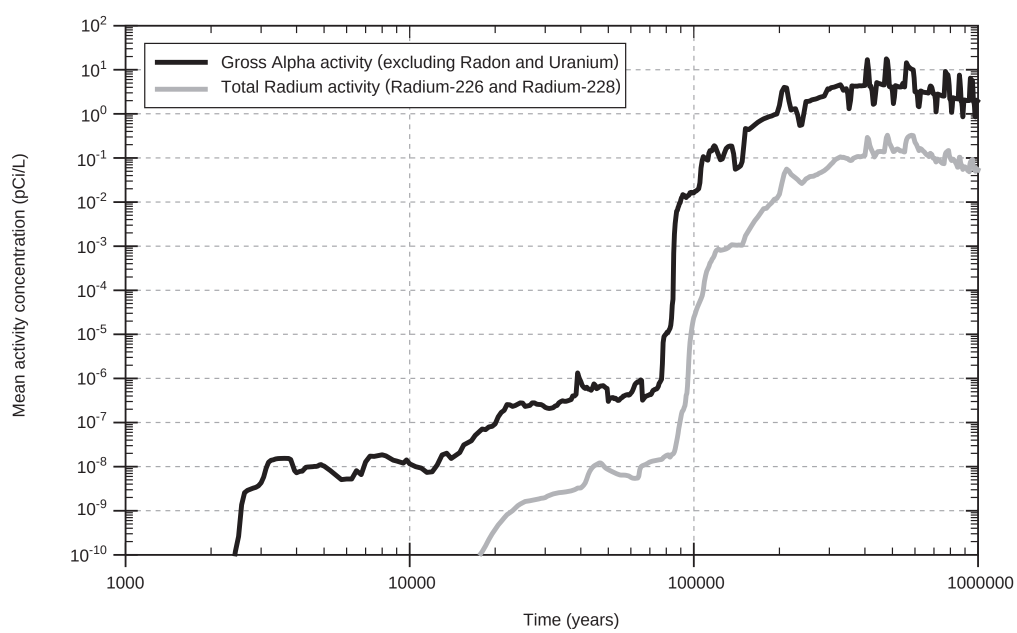
Figure I-21. Total mean annual individual dose at the RMEI location for the lower-temperature operating mode for the Proposed Action inventory under the igneous activity scenario; the figure displays the mean results for both the eruptive and intrusive events and the sum of these events as "Total Igneous."



Note: Use of logarithmic scale on both axes.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-12, p. 52.

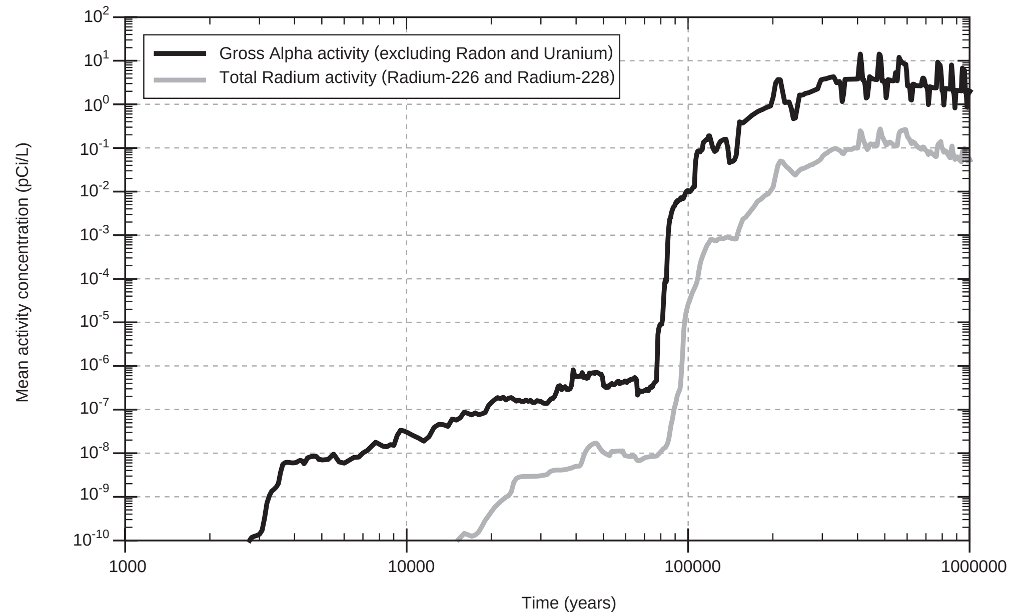
Figure I-22. Total annual individual dose at the RMEI location for 300 probabilistic simulations of the higher-temperature operating mode for the Proposed Action inventory under the human intrusion-at-30,000-years scenario; the figure also displays the median, mean, and 95th-percentile values of these simulations.



Note: Use of logarithmic scale on both axes.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-17, p. 57.

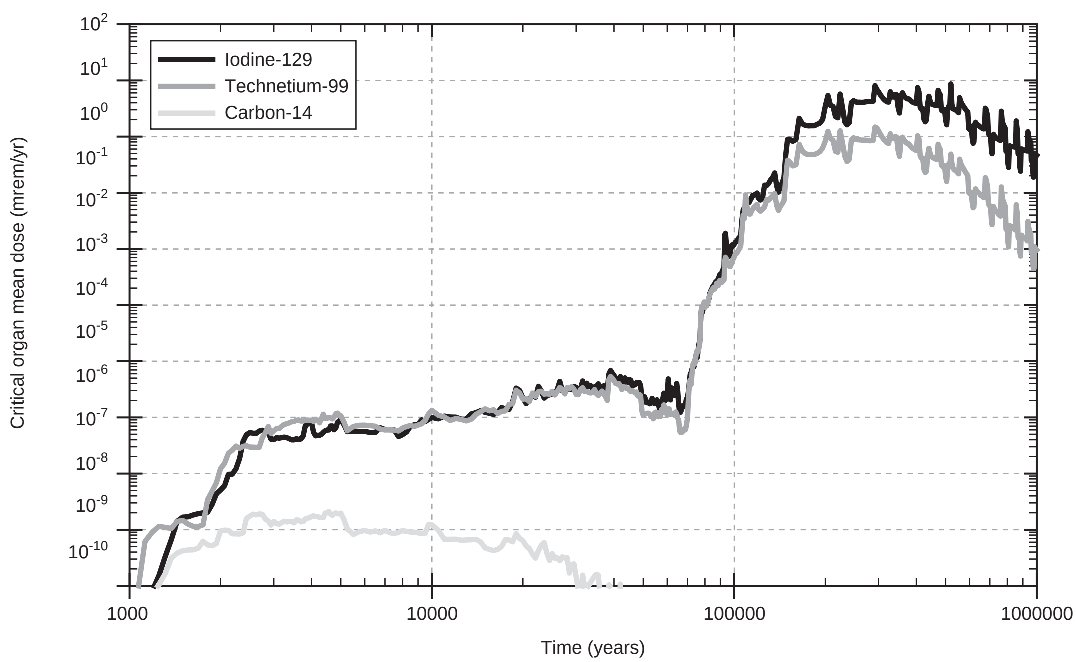
Figure I-23. Mean activity concentrations of gross alpha activity and total radium (radium-226 plus radium-228) at the RMEI location of 300 probabilistic simulations of the higher-temperature operating mode for the Proposed Action inventory for the nominal scenario.



Note: Use of logarithmic scale on both axes.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-18, p. 58.

Figure I-24. Mean activity concentrations of gross alpha activity and total radium (radium-226 plus radium-228) at the RMEI location of 300 probabilistic simulations of the lower-temperature operating mode for the Proposed Action inventory for the nominal scenario.



Note: Use of logarithmic scale on both axes.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-19, p. 59.

Figure I-25. Mean dose to critical organs for technetium-99, carbon-14, and iodine-129 at the RMEI location of 300 probabilistic simulations of the higher-temperature operating mode for the Proposed Action inventory for the nominal scenario.

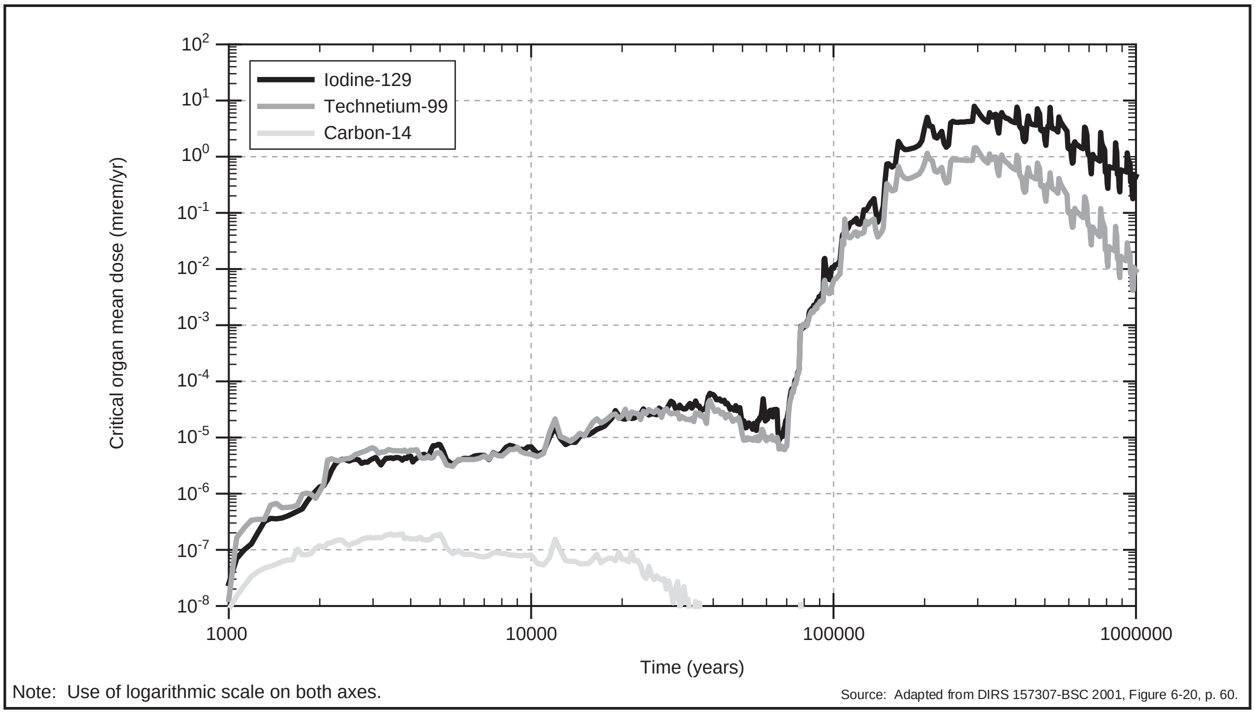


Figure I-26. Mean dose to critical organs for technetium-99, carbon-14, and iodine-129 at the RMEI location of 300 probabilistic simulations of the lower-temperature operating mode for the Proposed Action inventory for the nominal scenario.

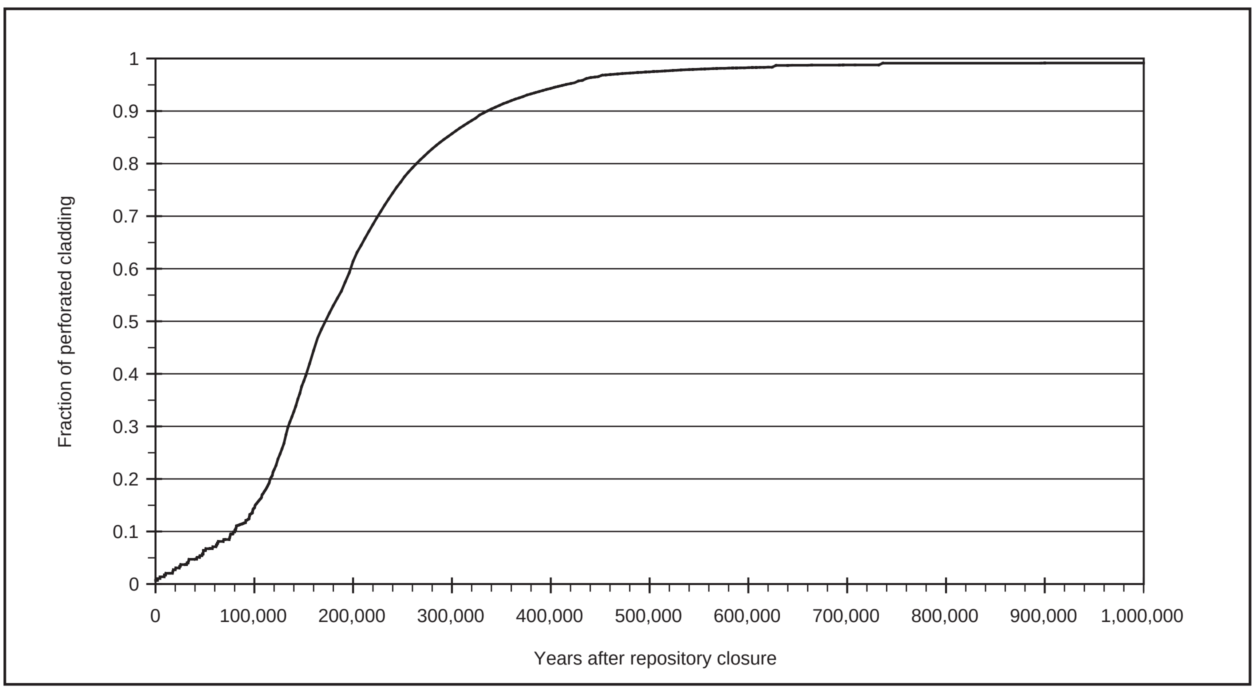


Figure I-27. Fraction of perforated cladding for commercial spent nuclear fuel as a function of time after repository closure.

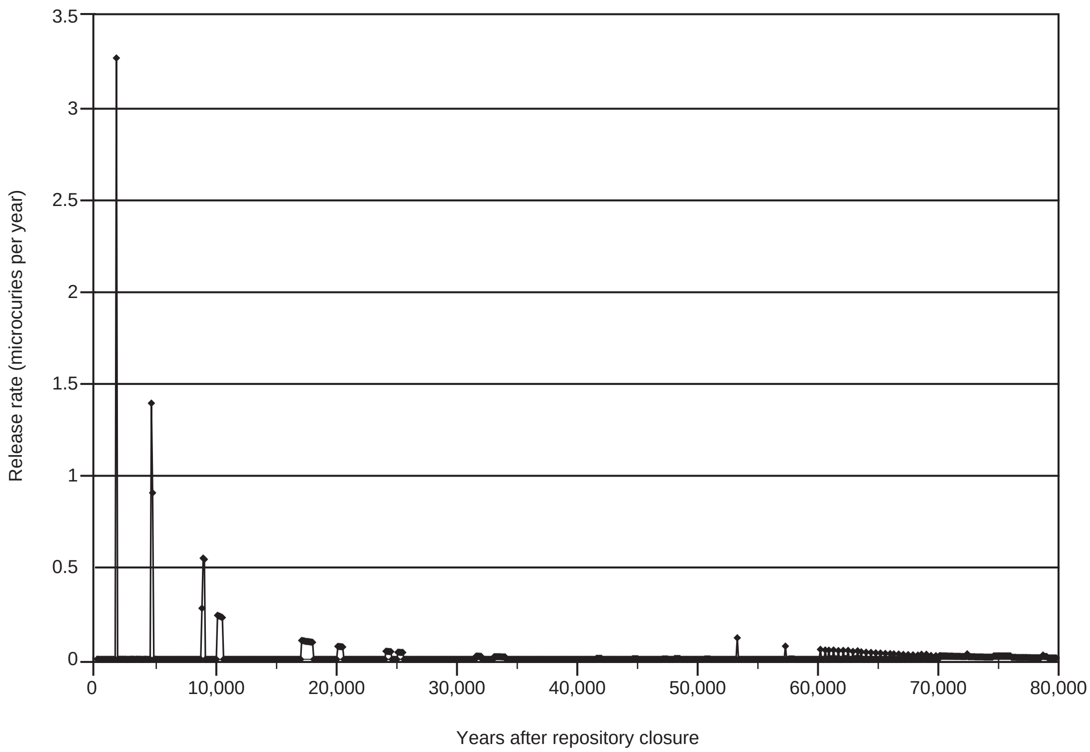
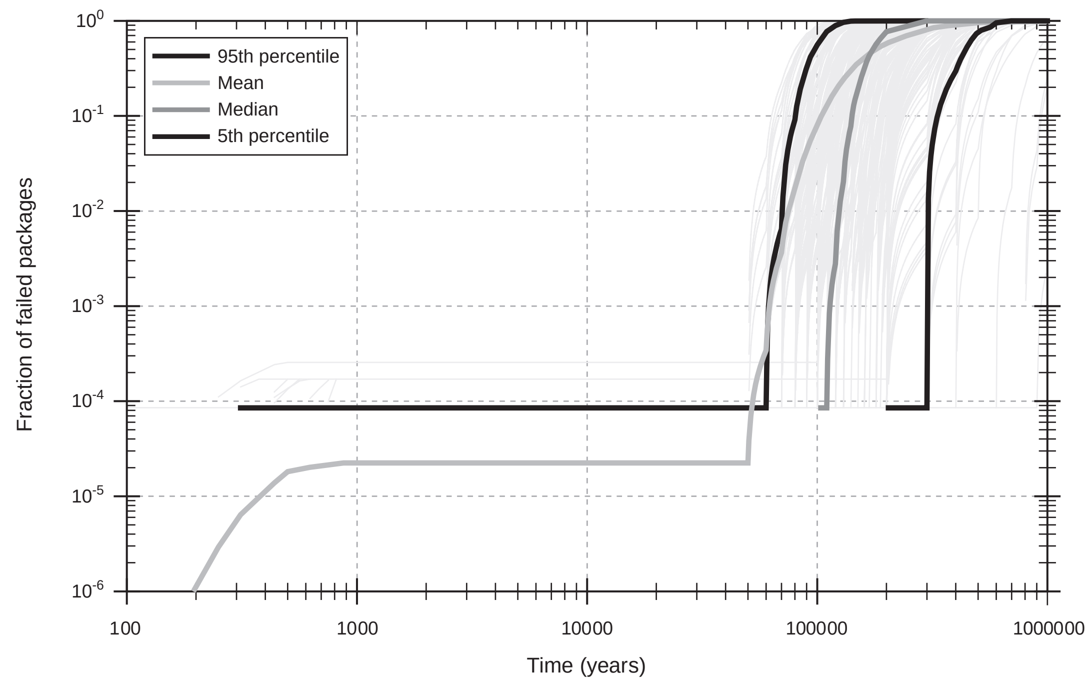


Figure I-28. Release rate of carbon-14 from the repository to the ground surface for 80,000 years following repository closure.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

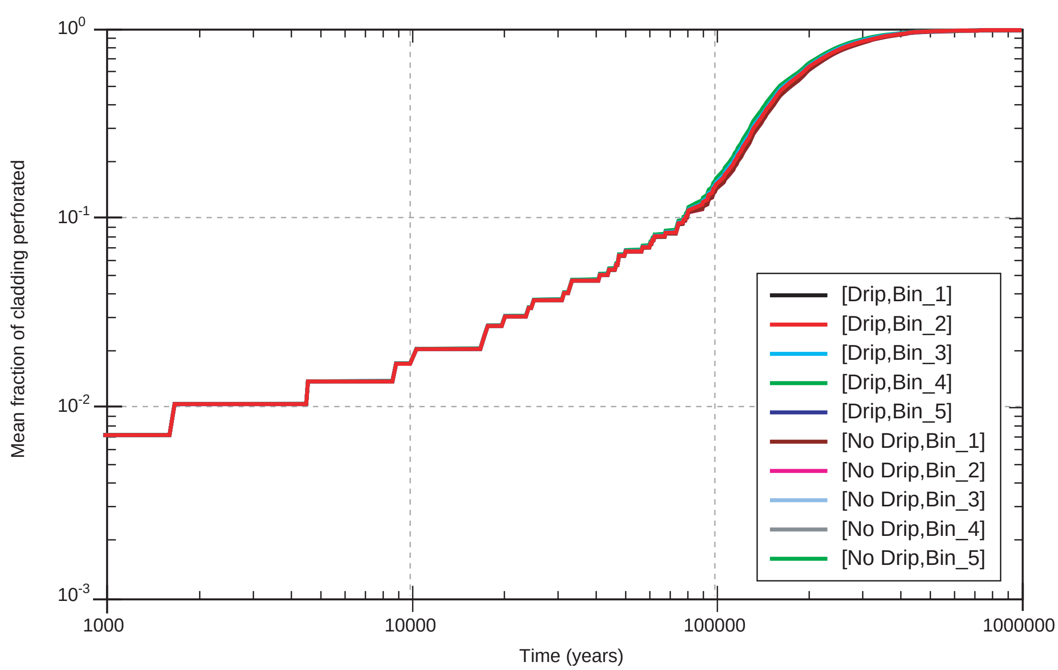
104328	ASTM 1998	ASTM (American Society for Testing and Materials) 1998. *Standard Specification for Low-Carbon Nickel-Molybdenum-Chromium, Low-Carbon Nickel-Chromium-Molybdenum, Low-Carbon Nickel-Chromium-Molybdenum-Copper and Low-Carbon Nickel-Chromium-Molybdenum-Tungsten Alloy Plate, Sheet, and Strip.* ASTM B 575-97. West Conshohocken, Pennsylvania: American Society for Testing and Materials. TIC: 241816.
100103	Bodvarsson, Bandurraga, and Wu 1997	Bodvarsson, G.S.; Bandurraga, T.M.; and Wu, Y.S., eds. 1997. *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment.* LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971014.0232.



Note: Use of logarithmic scale on both axes.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-1, p. 38.

Figure I-8. Waste package failure curves for 300 probabilistic simulations for the Proposed Action inventory; the figure also displays the 5th-percentile, median, mean, and 95th-percentile values of these simulations.



Note: Use of logarithmic scale on both axes. All curves plot over one another when using a log scale for the y-axis.

Source: Adapted from DIRS 157307-BSC 2001, Figure 6-2, p. 39.

Figure I-9. Cladding failure profile for the Proposed Action inventory.

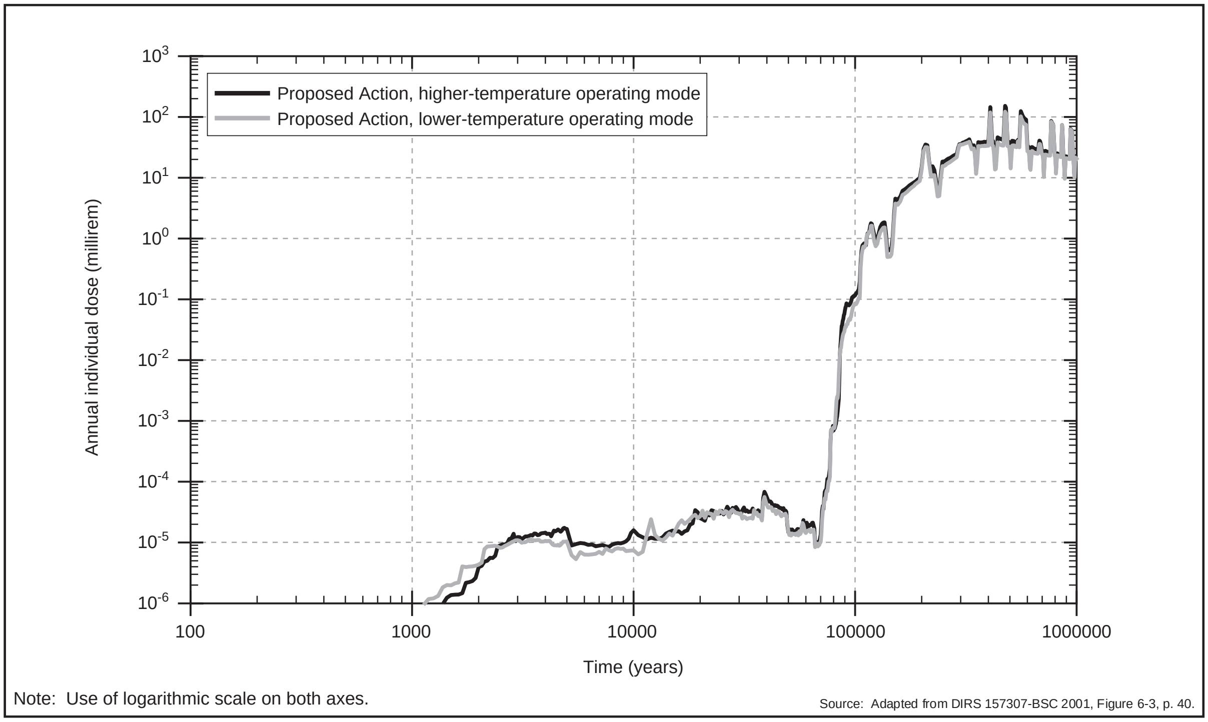


Figure I-10. Comparison plot of the total mean annual individual dose at the RMEI location under the higher-temperature and lower-temperature operating modes for the Proposed Action inventory, nominal scenario.

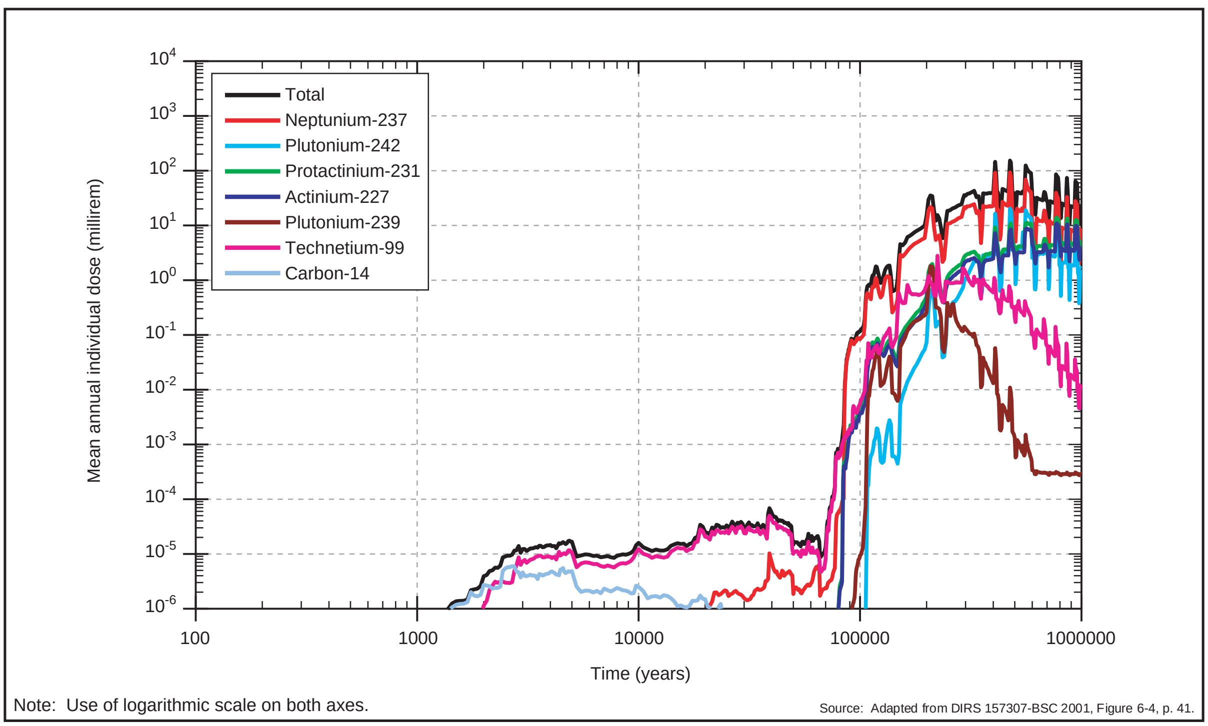


Figure I-11. Total and individual radionuclide mean annual dose to an individual at the RMEI location for the higher-temperature operating mode for the Proposed Action inventory, nominal scenario.

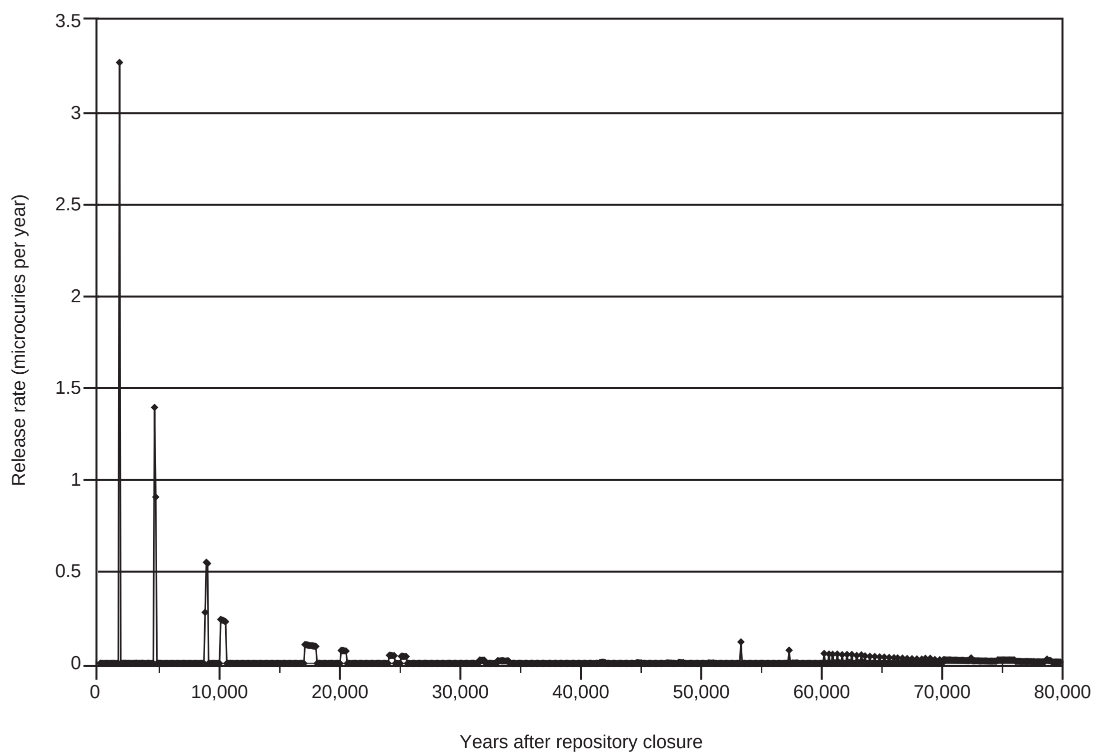


Figure I-28. Release rate of carbon-14 from the repository to the ground surface for 80,000 years following repository closure.

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100103	Bodvarsson, Bandurraga, and Wu 1997	Bodvarsson, G.S.; Bandurraga, T.M.; and Wu, Y.S., eds. 1997. *The Site-Scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment.* LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971014.0232.

152059	BSC 2001	BSC (Bechtel SAIC Company) 2001. *Performance Assessment of U.S. Department of Energy Spent Fuels in Support of Site Recommendation.* CAL-WIS-PA-000002 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010627.0026.
153909	BSC 2001	BSC (Bechtel SAIC Company) 2001. *Waste Package Radionuclide Inventory Approximations for TSPA-SR.* CAL-WIS-MD-000004 REV 00 ICN 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010227.0015.
154659	BSC 2001	BSC (Bechtel SAIC Company) 2001. *FY01 Supplemental Science and Performance Analyses, Volume 2: Performance Analyses.* TDR-MGR-PA-000001 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20010724.0110.
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APPENDIX J. TRANSPORTATION

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The appendix describes the key data and assumptions DOE used in the analyses and the analysis tools and methods the Department used to estimate impacts of loading operations at 72 commercial and 5 DOE sites; incident-free transportation by highway, rail and barge; intermodal transfer; and transportation accidents. The references listed at the end of this appendix contain additional information.

This appendix presents information on analyses of the impacts of national transportation and on analyses of the impacts that could occur in Nevada. Section J.1 presents information on the analysis of occupational and public health and safety impacts for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository. Section J.2 presents information on the analysis of rail and intermodal transportation alternatives. Section J.3 presents information on the analysis of transportation in Nevada. Section J.4 presents state-specific transportation impacts and maps of analyzed state-specific transportation routes.

J.1 Methods Used To Estimate Potential Impacts of Transportation

This section provides information on the methods and data DOE used to estimate impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial sites and 5 DOE sites throughout the United States to the Yucca Mountain Repository.

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department would prefer most shipments to a Yucca Mountain repository be made using rail transportation. It also expects that the mostly rail scenario described in this EIS best represents the mix of rail and truck transportation that would be used. However, it cannot be certain of the actual mix of rail and truck transportation that would occur over the 24 years of the Proposed Action. Consequently, DOE used the mostly legal-weight truck and mostly rail scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. The estimated number of shipments for the mostly legal-weight truck and mostly rail scenarios represents the two extremes in the possible mix of transportation modes, thereby covering the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

J.1.1 ANALYSIS APPROACH AND METHODS

Three types of impacts could occur to the public and workers from transportation activities associated with the Proposed Action. These would be a result of the transportation of spent nuclear fuel and

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The appendix describes the key data and assumptions DOE used in the analyses and the analysis tools and methods the Department used to estimate impacts of loading operations at 72 commercial and 5 DOE sites; incident-free transportation by highway, rail and barge; intermodal transfer; and transportation accidents. The references listed at the end of this appendix contain additional information.

This appendix presents information on analyses of the impacts of national transportation and on analyses of the impacts that could occur in Nevada. Section J.1 presents information on the analysis of occupational and public health and safety impacts for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository. Section J.2 presents information on the analysis of rail and intermodal transportation alternatives. Section J.3 presents information on the analysis of transportation in Nevada. Section J.4 presents state-specific transportation impacts and maps of analyzed state-specific transportation routes.

J.1 Methods Used To Estimate Potential Impacts of Transportation

This section provides information on the methods and data DOE used to estimate impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial sites and 5 DOE sites throughout the United States to the Yucca Mountain Repository.

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department would prefer most shipments to a Yucca Mountain repository be made using rail transportation. It also expects that the mostly rail scenario described in this EIS best represents the mix of rail and truck transportation that would be used. However, it cannot be certain of the actual mix of rail and truck transportation that would occur over the 24 years of the Proposed Action. Consequently, DOE used the mostly legal-weight truck and mostly rail scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. The estimated number of shipments for the mostly legal-weight truck and mostly rail scenarios represents the two extremes in the possible mix of transportation modes, thereby covering the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

J.1.1 ANALYSIS APPROACH AND METHODS

Three types of impacts could occur to the public and workers from transportation activities associated with the Proposed Action. These would be a result of the transportation of spent nuclear fuel and high-level radioactive waste and of the personnel, equipment, materials, and supplies needed to construct, operate and monitor, and close the proposed Yucca Mountain Repository. The first type, radiological impacts, would be measured by radiological dose to populations and individuals and the resulting estimated number of latent cancer fatalities that would be caused by radiation from shipments of spent nuclear fuel and high-level radioactive waste from the 77 sites under normal and accident transport conditions. The second and third types would be nonradiological impacts—potential fatalities resulting from vehicle emissions and caused by vehicle accidents. The analysis also estimated impacts due to the characteristics of hazardous cargoes from accidents during the transportation of nonradioactive hazardous materials to support repository construction, operation and monitoring, and closure. For perspective, about 11 fatalities resulting from hazardous material occur each year during the transportation of more than 300 million shipments of hazardous materials in the United States (DIRS 156755-BLS 2001, Table A-8). Therefore, DOE expects that the risks from exposure to hazardous materials that could be released during shipments to and from the repository sites would be very small (see Section J.1.4.2.4). The analysis evaluated the impacts of traffic accidents and vehicle emissions arising from these shipments.

The analysis used a step-wise process to estimate impacts to the public and workers. The process used the best available information from various sources and computer programs and associated data to accomplish the steps. Figures J-1 and J-2 show the steps followed in using data and computer programs. DOE has determined that the computer programs identified in the figure are suitable, and provide results in the appropriate measures, for the analysis of impacts performed for this EIS.

The CALVIN computer program (DIRS 155644-CRWMS M&O 1999, all) was used to estimate the numbers of shipments of spent nuclear fuel from commercial sites. This program used information on spent nuclear fuel stored at each site and an assumed scenario for picking up the spent fuel from each site. The program also used information on the capacity of shipping casks that could be used.

The HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) is a routing tool used to select existing highway routes that would satisfy U.S. Department of Transportation route selection regulations and that DOE could use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) is a routing tool used to select existing rail routes that railroads would be likely to use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The RADTRAN 5 computer program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) was used in estimating the radiological doses and dose risks to populations and transportation workers resulting from incident-free transportation and to the general population from accident scenarios. For the analysis of incident-free transportation risks, the code used scenarios for persons who would share transportation routes with shipments—called *onlink populations*, persons who live along the route of travel—*offlink populations*, and persons exposed at stops. For accident risks, the code evaluated the range of possible accident scenarios from high probability and low consequence to low probability and high consequence.

The RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) was used to estimate radiological doses to maximally exposed individuals for incident-free transportation and to populations and maximally exposed individuals for accident scenarios. To estimate incident-free doses to maximally exposed individuals, RISKIND used geometry to calculate the dose rate at specified locations that would arise from a source of radiation. RISKIND was also used to calculate the radiation dose to a population and hypothetical maximally exposed individuals from releases of radioactive materials postulated to occur in maximum reasonably foreseeable accident scenarios.

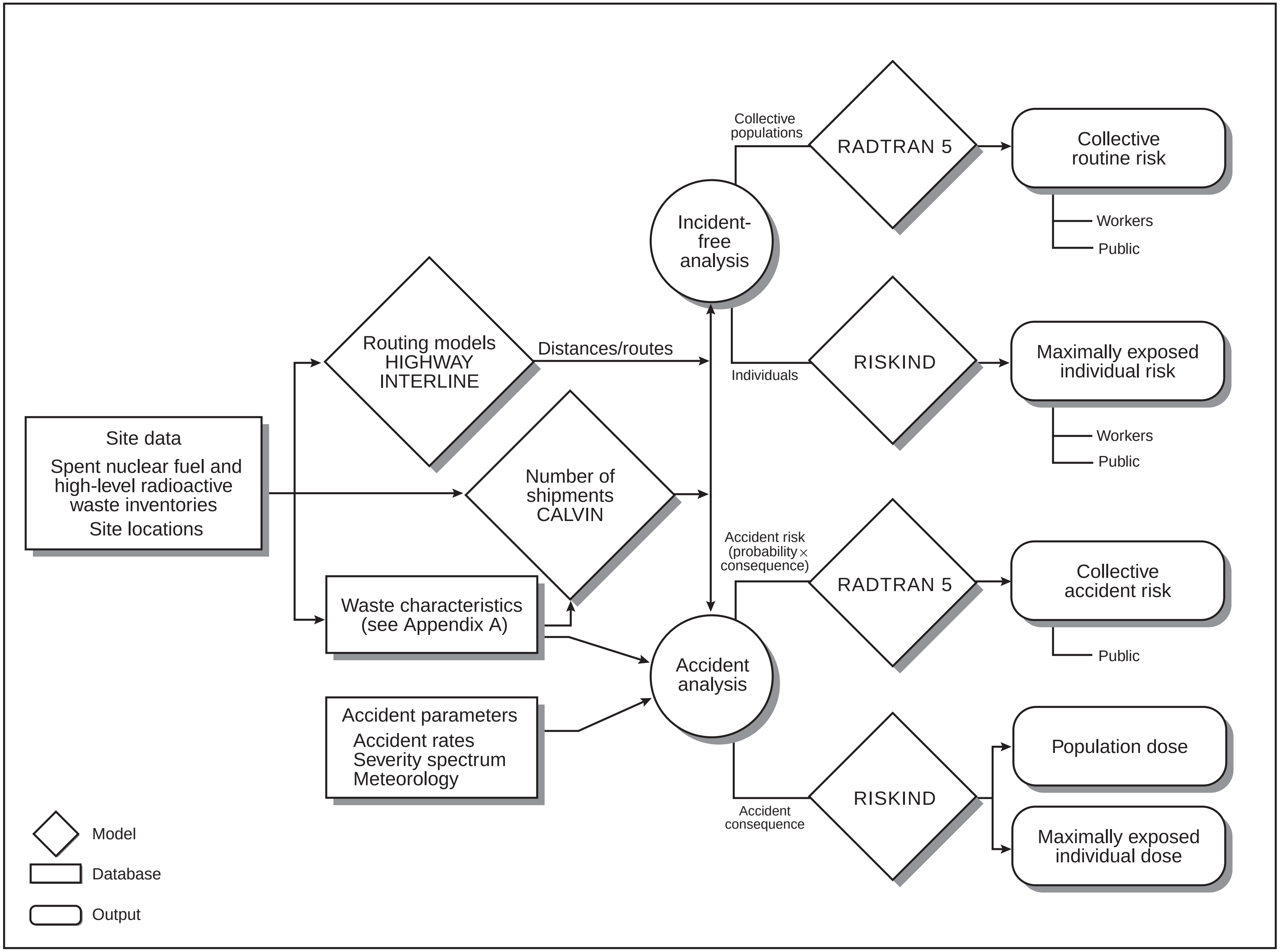

Figure J-1. Methods and approach for analyzing transportation radiological health risk.

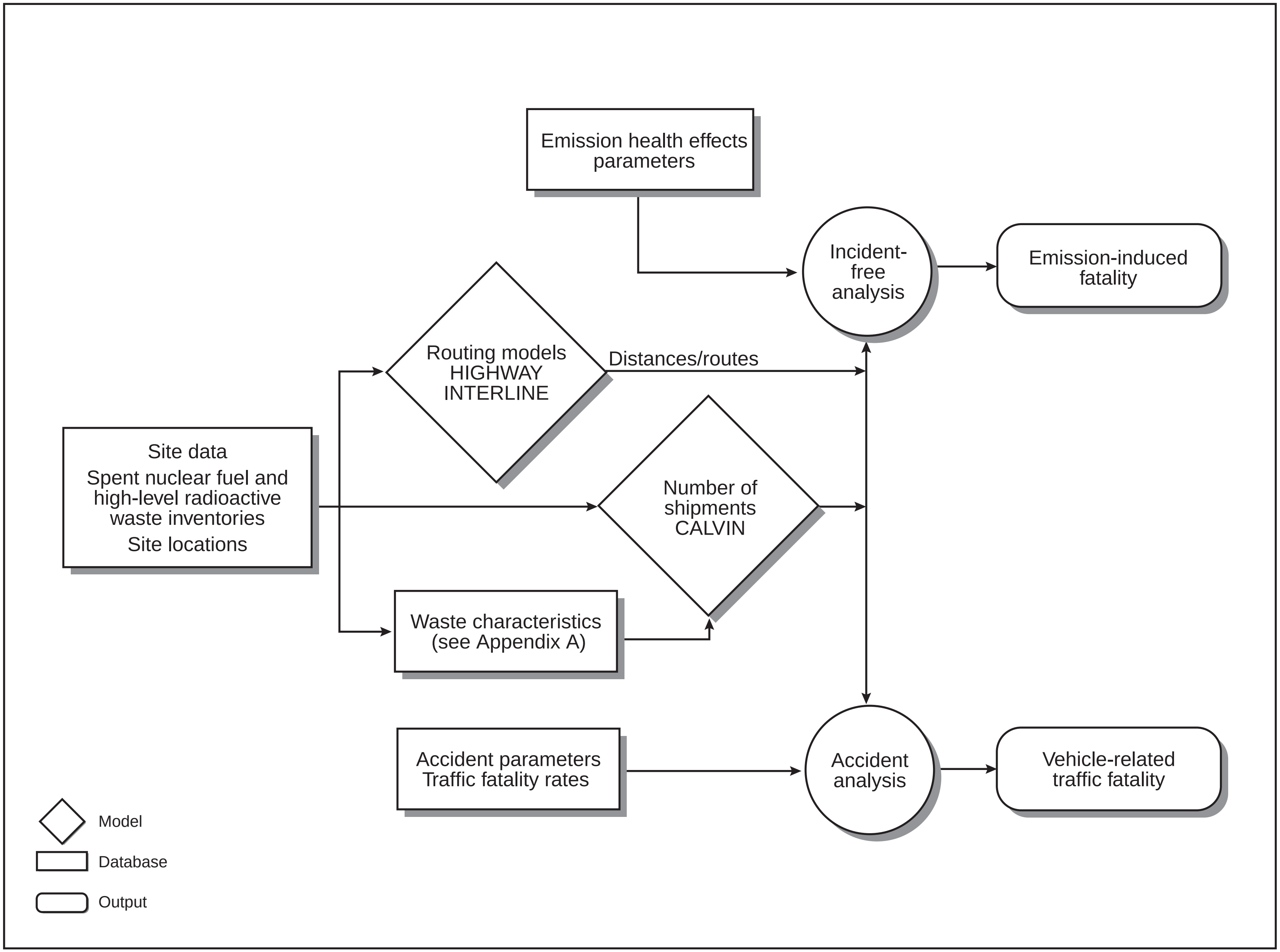

Figure J-2. Methods and approach for analyzing transportation nonradiological health risk.

DOSE RISK

Dose risk is a measure of radiological impacts to populations – public or workers – from the potential for exposure to radioactive materials. Thus, a potential of 1 chance in 1,000 of a population receiving a collective dose of 1 rem (1 person-rem) from an accident would result in a dose risk of 0.001 person-rem (0.001 is the product of 1 person-rem and the quotient of 1 over 1,000). The risk of latent cancer fatalities (a commonly used measure of radiological impact to populations) is obtained by multiplying the dose risk (in person-rem) by a conversion factor of 0.0005 fatal cancer per person-rem for the public. For workers, the conversion factor is 0.0004 fatal cancer per person-rem.

The use of dose risk to measure radiological impacts allows a comparison of alternatives with differing characteristics in terms of radiological consequences that could result and the likelihood that the consequences would actually occur.

The following sections describe these programs in detail.

J.1.1.1 CALVIN

The Civilian Radioactive Waste Management System Analysis and Logistics Visually Interactive (CALVIN) model (DIRS 155644-CRWMS M&O 1999, all) was developed to be a planning tool to estimate the logistic and cost impacts of various operational assumptions for accepting radioactive wastes. CALVIN was used in transportation modeling to determine the number of shipments of commercial spent nuclear fuel from each reactor site. The parameters that the CALVIN model used to determine commercial spent nuclear fuel movement include the shipping cask specifications including heat limits, $k_{infinity}$ (measure of criticality) limits for the contents of the casks, capacity (assemblies or canisters/cask), burnup/enrichment curves, and cooling time for the fuel being shipped.

The source data used by CALVIN for commercial spent nuclear fuel projections include the RW-859 historic data collected by the Energy Information Administration, and the corresponding projection produced based on current industry trends for commercial fuel (see Appendix A). This EIS used CALVIN to estimate commercial spent nuclear fuel shipment numbers based on the cask capacity (see Section J.1.2) and the shipping cask handling capabilities at each site. For the mostly rail national transportation scenario, CALVIN assumed that shipments would use the largest cask a site would be capable of handling. In some cases the analysis, using CALVIN, estimated that the characteristics of the spent nuclear fuel that would be picked up at a site (principally the estimated heat generation rate) would limit the number of fuel assemblies that could be transported to fewer than the full capacity of the cask. In such cases, to provide a realistic estimate of the number of shipments that would be made, CALVIN assumed the cask would contain the smaller number of assemblies. The reduction in capacity was sufficient to accommodate the characteristics of the spent nuclear fuel the program estimated for pickup at the site. In addition, the analysis assumed that sites without sufficient crane capacity to handle a rail cask while operational would be upgraded after reactor shutdown such that the sites could handle rail casks.

J.1.1.2 HIGHWAY

The HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) was used to select highway routes for the analysis of impacts presented in this EIS. Using data for actual highways and rules that apply to carriers of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101), HIGHWAY selected highway routes for legal-weight truck shipments from each commercial and DOE site to the Yucca Mountain site. In addition, DOE used this program to estimate the populations within 800 meters (0.5 mile) of the routes it selected. These population densities were used in calculating incident-free radiological risks to the public along the routes.

One of the features of the HIGHWAY model is its ability to estimate routes for the transport of Highway Route-Controlled Quantities of Radioactive Materials. The U.S. Department of Transportation has established a set of routing regulations for the transport of these materials (49 CFR 397.101). Routes following these regulations are frequently called HM-164 routes. The regulations require the transportation of these shipments on preferred highways, which include:

- Interstate highways
- An Interstate System bypass or beltway around a city
- State-designated preferred routes

State routing agencies can designate preferred routes as an alternative to, or in addition to, one or more Interstate highways. In making this determination, the state must consider the safety of the alternative preferred route in relation to the Interstate route it is replacing, and must register all such designated preferred routes with the U.S. Department of Transportation.

Frequently, the origins and destinations of Highway Route-Controlled Quantities of Radioactive Materials are not near Interstate highways. In general, the U.S. Department of Transportation routing regulations require the use of the shortest route between the pickup location to the nearest preferred route entry location and the shortest route to the destination from the nearest preferred route exit location. In general, HM-164 routes tend to be somewhat longer than other routes; however, the increased safety associated with Interstate highway travel is the primary purpose of the routing regulations.

Because many factors can influence the time in transit over a preferred route, a carrier of Highway Route-Controlled Quantities of Radioactive Materials must select a route for each shipment. Seasonal weather conditions, highway repair or construction, highways that are closed because of natural events (for example, a landslide in North Carolina closed Interstate 40 near the border with Tennessee from June until November 1997), and other events (for example, the 1996 Olympic Games in Atlanta, Georgia) are all factors that must be considered in selecting preferred route segments to reduce time in transit. For this analysis, the highway routes were selected by the HIGHWAY program using an assumption of normal travel and without consideration for factors such as seasons of the year or road construction delays. Although these shipments could use other routes, DOE considers the impacts determined in the analyses to be representative of other possible routings that would also comply with U.S. Department of Transportation regulations. Specific route mileages for truck transportation are presented in Section J.1.2.2.1.

In selecting existing routes for use in the analysis, the HIGHWAY program determined the length of travel in each type of population zone—rural, suburban, and urban. The program characterized rural, suburban, and urban population areas according to the following breakdown: rural population densities range from 0 to 54 persons per square kilometer (0 to 140 persons per square mile); the suburban range is 55 to 1,300 persons per square kilometer (140 to 3,300 persons per square mile); and urban is all population densities greater than 1,300 persons per square kilometer (3,300 persons per square mile). The population densities along a route used by the HIGHWAY program are derived from 1990 data from the Bureau of the Census. In addition, the analysis used results of the 2000 Census for state populations as well as population forecasts published by the Bureau of the Census in estimating radiological impacts to populations that would live along transportation routes (see Sections J.1.3.2.1 and J.1.4.2.1).

J.1.1.3 INTERLINE

Shipments of radioactive materials by rail are not subject to route restrictions imposed by regulations. For general freight rail service, DOE anticipates that railroads would route shipments of spent nuclear fuel and high-level radioactive waste to provide expeditious travel and the minimum practical number of interchanges between railroads. The selection of a route determines the potentially exposed population along the route as well as the expected frequency of transportation-related accidents. The analysis used the INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) to project the railroad routes that DOE would use to ship spent nuclear fuel and high-level radioactive waste from the sites to the Yucca Mountain site. Specific routes were projected for each originating generator with the exception of six that do not have capability to handle or load a rail transportation cask (see Section J.1.2.1.1). INTERLINE computes rail routes based on rules that simulate historic routing practices of U.S. railroads. The INTERLINE database consists of 94 separate subnetworks and represents various competing rail companies in the United States. The database, which was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974, has been expanded and modified extensively over the past two decades. The program is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations of commercial rail firms. The program also provides an estimate of the population within 800 meters (0.5 mile) of the routes it selected. This population estimate was used to calculate incident-free radiological risk to the public along the routes selected for analysis.

In general, rail routes are calculated by minimizing the value of a factor called *impedance* between the origin and the destination. The impedance is determined by considering trip distance along a route, the mainline classification of the rail lines that would be used, and the number of interchanges that would occur between different railroad companies involved. In general, impedance determined by the INTERLINE program:

- Decreases as the distance traveled decreases
- Is reduced by use of mainline track that has the highest traffic volume (see below)
- Is reduced for shipments that involve the fewest number of railroad companies

Thus, routes that are the most direct, that use high-traffic volume mainline track, and that involve only one railroad company would have the lowest impedance. The most important of these characteristics from a routing standpoint is the *mainline classification*, which is the measure of traffic volume on a particular link. The mainline classifications used in the INTERLINE routing model are as follows:

- A – mainline – more than 20 million gross ton miles per year
- B – mainline – between 5 and 20 million gross ton miles per year
- A – branch line – between 1 and 5 million gross ton miles per year
- B – branch line – less than 1 million gross ton miles per year

The INTERLINE routing algorithm is designed to route a shipment preferentially on the rail lines having the highest traffic volume. Frequently traveled routes are preferred because they are generally well maintained because the railroad depends on these lines for a major portion of its revenue. In addition, routing along the high-traffic lines usually replicates railroad operational practices.

The population densities along a route were derived from 1990 data from the Bureau of the Census, as described above for the HIGHWAY computer program. In addition, the analysis used the results of the 2000 Census for state populations as well as population forecasts published by the Bureau of the Census to estimate radiological impacts to populations that would live along transportation routes (see Sections J.1.3.2.1 and J.1.4.2.1).

DOE anticipates that routing of rail shipments in dedicated (special) train service, if used, would be similar to routing of general freight shipments for the same origin and destination pairs. However, because cask cars would not be switched between trains at classification yards, dedicated train service would be likely to result in less time in transit.

J.1.1.4 RADTRAN 5

DOE used the RADTRAN 5 computer program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) in conjunction with a Microsoft Access database for the routine and accident cargo-related risk assessment to estimate radiological impacts to collective populations. The Department used RADTRAN 5 to generate risk factors such as transportation impacts per kilometer of travel. The database was used to manage the large amount of data and results for the analysis. Sandia National Laboratories developed RADTRAN 5 to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The RADTRAN codes, which have been reviewed and updated periodically, have been used extensively by DOE for transportation risk assessment since the late 1970s. In 1995, DIRS 101845-Maheras and Pippen (1995, p. iii) conducted an analysis “to validate the estimates made by” selection of computer codes used to estimate radiation doses from the transportation of radioactive materials. The RADTRAN 4 computer code was included in the analysis. The analysis demonstrated that the RADTRAN 4 code, an earlier version of RADTRAN 5 yielded acceptable results. In the context of this analysis, “acceptable results” means that the differences between the estimates generated by the RADTRAN 4 code and hand calculations were small [that is, less than 5 percent (DIRS 101845-Maheras and Pippen 1995, p. 3-1)]. DIRS 153967-Steinman and Kearfott (2000, all) compared RADTRAN 5 results to measured radiation doses from moving sources, and found that RADTRAN 5 overpredicts the measured radiation dose to the receptor.

The RADTRAN 5/database calculations for routine (or incident-free) dose are based on expressing the dose rate as a function of distance from a point source. Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of the exposure, vehicle speed, stopping time, traffic density, and route characteristics such as population density and route segment length. The radiation dose to the exposed population decreases as the source-receptor distance and the vehicle speed increase. The radiation dose to the exposed population increases as the other parameters mentioned above increase. In calculating population doses from incident-free transportation, RADTRAN 5 and the database used population density data provided by the HIGHWAY and INTERLINE computer programs. These data are based on the 1990 Census. The results of the RADTRAN 5/database analyses were escalated to account for population growth to 2035.

In addition to routine doses, the RADTRAN 5/database combination was used to estimate dose risk from a spectrum of accident scenarios. This spectrum encompasses the range of possible accidents, including low-probability accident scenarios that have high consequences, and high-probability accident scenarios that have low consequences (fender benders). The RADTRAN 5/database calculation of collective accident risks for populations along routes employed models that quantified the range of potential accident severities and the responses of the shipping casks to those scenarios. The spectrum of accident severity was divided into categories. Each category of severity has a conditional probability of occurrence; that is, the probability that an accident will be of a particular severity if it occurs. A release fraction, which is the fraction of the material in a shipping cask that could be released in an accident, is assigned to each accident scenario severity category on the basis of the physical and chemical form of the material being transported. The analysis also considered accidents that would lose lead radiation shielding but with no release of radioactive material. The model also considers the mode of transportation, the state-specific accident rates, and population densities for rural, suburban, and urban population zones through which shipments would pass to estimate accident risks for this analysis. The

RADTRAN 5/database calculation used actual population densities within 800 meters (0.5 mile) of the transportation routes based on 1990 Census data to estimate populations within 80 kilometers (50 miles).

For accident scenarios involving releases of radioactive material, RADTRAN 5 assumes that the material is dispersed in the environment (as described by a Gaussian dispersion model). The dispersion analysis assumed that meteorological conditions are national averages for wind speed and atmospheric stability. For the risk assessment, the analysis used these meteorological conditions and assumed an instantaneous ground-level release and a small-diameter source cloud (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, Section 4.1.1). The calculation of the collective population dose following the release and the dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud
- External exposure to contaminated ground
- Internal exposure from inhalation of airborne contaminants
- Internal exposure from ingestion of contaminated food

For the ingestion pathway, the analysis used the ground deposition calculated using RADTRAN 5 and state-specific food transfer factors, which relate the amount of radioactive material ingested to the amount deposited on the ground, as input to the database. Radiation doses from the ingestion or inhalation of radionuclides were calculated by using standard dose conversion factors from Federal Guidance Reports No. 11 and 12 (DIRS 104800-CRWMS M&O 1999, p. 36).

POTENTIAL HUMAN HEALTH IMPACTS OF TRANSPORTATION ACCIDENTS THAT COULD CONTAMINATE SURFACE-WATER AND GROUNDWATER RESOURCES

The EIS does not specifically analyze a transportation accident involving contamination of surface water or groundwater. Analyses performed in previous EISs (see Chapter 1, Section 1.5.3 and Table 1-1) have consistently shown that the airborne pathway has the greatest potential for exposing large numbers of people to radioactive material in the event of a release of such material during a severe transportation accident. A paper by R.M. Ostmeyer analyzed the potential importance of water pathway contamination for spent nuclear fuel transportation accident risk using a worst-case water contamination scenario. The analysis showed that the impacts of the water contamination scenario were about 1/50th of the impacts of a comparable accident in an urban area (DIRS 104784-Ostmeyer 1986, all).

J.1.1.5 RISKIND

The RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) was used as a complement to the RADTRAN 5 calculations to estimate scenario-specific doses to maximally exposed individuals for both routine operations and accident conditions and to estimate population impacts for the assessment of accident scenario consequences. The RISKIND code was originally developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups from the transportation of spent nuclear fuel and is used now to analyze the transport of other radioactive materials, as well as spent nuclear fuel.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the ground and air. RISKIND was used to calculate the dose as a function of distance from a shipment on the basis of the dimensions of the shipment (millirem per hour for stationary exposures and millirem per event for moving shipments). The code approximates the shipment as a cylindrical volume source, and the calculated dose includes contributions from secondary radiation scatter from buildup (scattering by material contents), cloudshine (scattering by air), and groundshine (scattering by the ground). Credit for potential shielding between the shipment and the receptor was not considered.

The RISKIND code was also used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents. Whereas the RADTRAN 5 risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND consequence assessment focuses on accident scenarios that result in the largest releases of radioactive material to the environment that are reasonably foreseeable. The consequence assessment was intended to provide an estimate of the potential impacts posed by a severe, but highly unlikely, transportation-related accident scenario.

The dose to each maximally exposed individual considered was calculated with RISKIND for an exposure scenario defined by a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations were similar to those given in previous transportation risk assessments. The scenarios were not meant to be exhaustive but were selected to provide a range of potential exposure situations.

J.1.2 NUMBER AND ROUTING OF SHIPMENTS

This section discusses the number of shipments and routing information used to analyze potential impacts that would result from preparation for and conduct of transportation operations to ship spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Table J-1 summarizes the estimated numbers of shipments for the various inventory and national shipment scenario combinations.

J.1.2.1 Number of Shipments

DOE used two analysis scenarios—mostly legal-weight truck and mostly train (rail)—as bases for estimating the number of shipments of spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites. The number of shipments for the scenarios was used in analyzing transportation impacts for the Proposed Action and Inventory Modules 1 and 2. DOE selected the scenarios because, more than 10 years before the projected start of operations at the repository, it cannot accurately predict the actual mix of rail and legal-weight truck transportation that would occur from the 77 sites to the repository. Therefore, the selected scenarios enable the analysis to bound (or bracket) the ranges of legal-weight truck and rail shipments that could occur.

The analysis estimated the number of shipments from commercial sites where spent nuclear fuel would be loaded and shipped and from DOE sites where spent nuclear fuel, naval spent nuclear fuel, and high-level radioactive waste would be loaded and shipped.

For the mostly legal-weight truck scenario, with one exception, shipments were assumed to use legal-weight trucks. Overweight, overdimensional trucks weighing between about 36,300 and 52,200 kilograms (80,000 and 115,000 pounds) but otherwise similar to legal-weight trucks could be used for some spent nuclear fuel and high-level radioactive waste (for example, spent nuclear fuel from the South Texas reactors). The exception that gives the scenario its name—mostly legal-weight truck—was for shipments of naval spent nuclear fuel. Under this scenario, naval spent nuclear fuel would be shipped by rail, as decided in the *Record of Decision for a Dry Storage Container System for the Management of Naval Spent Nuclear Fuel* (62 *FR* 1095; January 8, 1997).

For the mostly rail scenario, the analysis assumed that all sites would ship by rail, with the exception of those with physical limitations that would make rail shipment impractical. The exception would be for shipments by legal-weight trucks from six commercial sites that do not have the capability to load rail casks. However, the analysis also assumed that these six sites would be upgraded to handle a rail cask after the reactors were shut down and would ship either by direct rail or by heavy-haul truck or barge to (scattering by material contents), cloudshine (scattering by air), and groundshine (scattering by the ground). Credit for potential shielding between the shipment and the receptor was not considered.

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Table J-1. Summary of estimated number of shipments for the various inventory and national transportation analysis scenario combinations.

	Mostly truck		Mostly rail	
	Truck	Rail	Truck	Rail
Proposed Action				
Commercial spent nuclear fuel	41,001	0	1,079	7,218
High-level radioactive waste	8,315	0	0	1,663
DOE spent nuclear fuel	3,470	300	0	765
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Proposed Action totals	*52,786*	*300*	*1,079*	*9,646*
Module 1[a]				
Commercial spent nuclear fuel	79,684	0	3,122	12,989
High-level radioactive waste	22,280	0	0	4,458
DOE spent nuclear fuel	3,721	300	0	796
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Module 1 totals	*105,685*	*300*	*3,122*	*18,243*
Module 2[a]				
Commercial spent nuclear fuel	79,684	0	3,122	12,989
High-level radioactive waste	22,280	0	0	4,458
DOE spent nuclear fuel	3,721	300	0	796
Greater-Than-Class-C waste	1,096	0	0	282
Special-Performance-Assessment-Required waste	1,763	55	0	410
Module 2 totals	*108,544*	*355*	*3,122*	*18,935*

a. The number of shipments for Module 1 includes all shipments of spent nuclear fuel and high-level radioactive waste included in the Proposed Action and shipments of additional spent nuclear fuel and high-level radioactive waste as described in Appendix A. The number of shipments for Module 2 includes all the shipments in Module 1 and additional shipments of highly radioactive materials described in Appendix A.

nearby railheads. Of these six sites, two are direct rail sites and four are indirect rail sites. Of the four indirect rail sites, three are adjacent to navigable waterways and could ship by barge. In addition, under this scenario, the analysis assumed that 24 commercial sites that do not have direct rail service but that could handle large casks would ship by barge or heavy-haul truck to nearby railheads with intermodal capability.

For commercial spent nuclear fuel, the CALVIN code was used to compute the number of shipments. The number of shipments of DOE spent nuclear fuel and high-level radioactive waste was estimated based on the data in Appendix A and information provided by the DOE sites. The numbers of shipments were estimated based on the characteristics of the materials shipped, mode interface capability (for example, the lift capacity of the cask-handling crane) of each shipping facility, and the modal-mix case analyzed. Table J-2 summarizes the basis for the national and Nevada transportation impact analysis.

Detailed descriptions of spent nuclear fuel and high-level radioactive waste that would be shipped to the Yucca Mountain site are presented in Appendix A.

J.1.2.1.1 *Commercial Spent Nuclear Fuel*

For the analysis, the CALVIN model used 31 shipping cask configurations: 9 for legal-weight truck casks (Figure J-3) and 22 for rail casks (Figure J-4). Table J-3 lists the legal-weight truck and rail cask configurations used in the analysis and their capacities. The analysis assumed that all shipments would use one of the 31 configurations. If the characteristics of the spent nuclear fuel projected for shipment

Table J-2. Analysis basis—national and Nevada transportation scenarios.[a,b]

Material	Mostly legal-weight truck scenario national and Nevada	National mostly rail scenario	
		Nevada rail scenario	Nevada heavy-haul truck scenario
Casks			
Commercial SNF	Truck casks – about 1.8 MTHM per cask	Rail casks – 6 to 12 MTHM per cask for shipments from 66 sites	Rail casks – 6 to 12 MTHM per cask for shipments from 66 sites
		Truck casks – about 1.8 MTHM per cask for shipments from 6 sites[c]	Truck casks – about 1.8 MTHM per cask for shipments from 6 sites
DOE HLW and DOE SNF, except naval SNF	Truck casks – 1 SNF or HLW canister per cask	Rail casks – four to nine SNF or HLW canisters per cask	Rail casks – four to nine SNF or HLW canisters per cask
Naval SNF	Disposal canisters in large rail casks for shipment from INEEL	Disposable canisters in large rail casks for shipments from INEEL	Disposable canisters in large rail casks for shipments from INEEL
Transportation modes			
Commercial SNF	Legal-weight trucks	Direct rail from 49 sites served by railroads to repository	Rail from 49 sites served by railroads to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks from 7 sites to railhead, then rail to repository	Heavy-haul trucks from 7 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks or barges[d] from 17 sites to railhead, then rail to repository	Heavy-haul trucks or barges[d] from 17 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Legal-weight trucks from 6 sites to repository[c]	Legal-weight trucks from 6 sites to repository[c]
DOE HLW and DOE SNF, except naval SNF	Legal-weight trucks	Rail from DOE sites[e] to repository	Rail from DOE sites[e] to intermodal transfer station in Nevada, then heavy-haul trucks to repository
Naval SNF	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository	Rail from INEEL to repository	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository

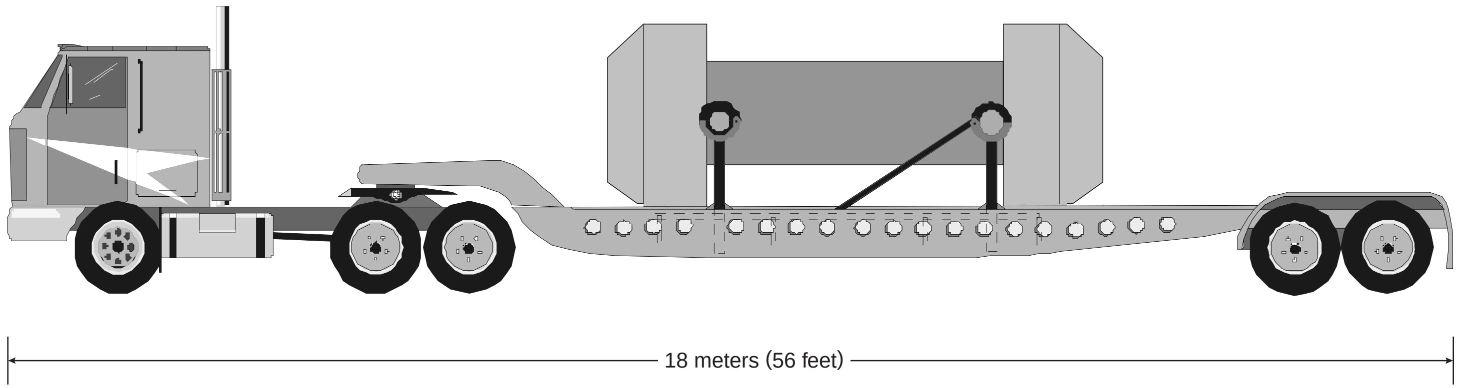
a. Abbreviations: SNF = spent nuclear fuel; MTHM = metric tons of heavy metal; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory.

b. G. E. Morris facility is included with the Dresden reactor facilities in the 72 commercial sites.

c. The analysis assumed that the six legal-weight truck sites would upgrade their crane capacity upon reactor shutdown and would ship all remaining spent nuclear fuel by rail. Of those six sites, four are heavy-haul sites and two are direct rail sites. Three of the heavy-haul sites have barge capability (Pilgrim, St. Lucie 1, and Indian Point).

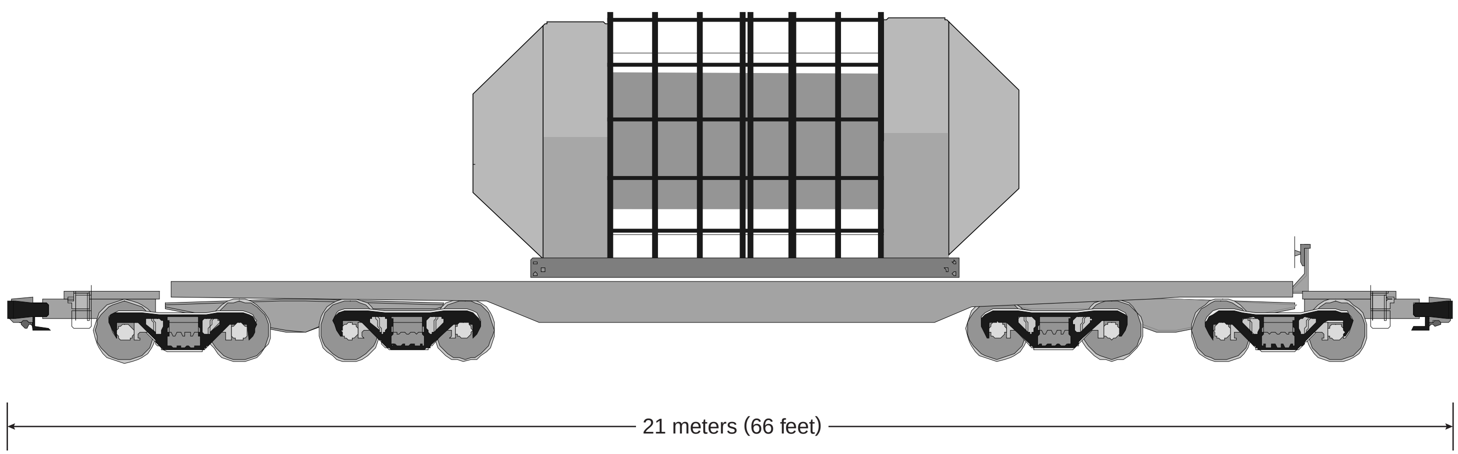
d. Seventeen of 24 commercial sites not served by a railroad are on or near a navigable waterway. Some of these 17 sites could ship by barge rather than by heavy-haul truck to a nearby railhead. Salem/Hope Creek treated as two sites for heavy-haul or barge analysis.

e. Hanford Site, Savannah River Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Ft. St. Vrain.



Source: DIRS 104782-Kelderhouse (1999, p. 7).

Figure J-3. Artist's conception of a truck cask on a legal-weight tractor-trailer truck.



Source: DIRS 104782-Kelderhouse (1999, p. 8).

Figure J-4. Artist's conception of a large rail cask on a railcar.

Table J-3. Shipping cask configurations.

Shipping cask	Capacity (number of spent nuclear fuel assemblies)	Description[a,b]
Rail		
B-R-32-SP	32	BWR single-purpose shipping container
B-R-32-SP-HH	32	BWR single-purpose high-heat-capacity shipping container
B-R-44-SP	44	Medium BWR single-purpose shipping container
B-R-68-OV	68	Large BWR overpack shipping container
B-R-68-SP	68	Large BWR single-purpose shipping container
B-R-BP64-OV	64	Plant-unique overpack shipping container
B-R-HI68-OV	68	BWR HISTAR overpack shipping container
B-R-NAC56-OV	56	BWR NAC UMS overpack shipping container
P-R-12-SP	12	Small PWR single-purpose shipping container
P-R-12-SP-HH	12	Small PWR single-purpose high-heat-capacity shipping container
P-R-21-SP	21	Medium PWR single-purpose shipping container
P-R-24-OV	24	Large PWR overpack shipping container
P-R-24-SP	24	Large PWR single-purpose shipping container
P-R-7-SP-HH	7	PWR high heat shipping container
P-R-9-OV-MOX	9	PWR mixed-oxide overpack shipping container
P-R-9-SP-MOX	9	PWR mixed-oxide single-purpose shipping container
P-R-MP24-OV	24	PWR MP-187 (large) overpack shipping container
P-R-NAC26-OV	26	PWR NAC UMS overpack shipping container
P-R-ST17-SP	17	PWR plant-unique single-purpose shipping container
P-R-VSC24-OV	24	PWR Transtor ventilated storage cask overpack shipping container
P-R-WES21-OV	21	PWR WESFLEX overpack shipping container
P-R-YR36-OV	36	PWR plant-unique overpack shipping container
Truck		
B-T-9/9-SP	9	BWR single-purpose shipping container
B-T-9/7-SP	7	Derated BWR single-purpose shipping container
P-T-4/4-SP	4	Primary PWR single-purpose shipping container
P-T-4/3-SP	3	Derated PWR single-purpose shipping container
P-T-4/2-SP	2	Derated PWR single-purpose shipping container
P-T-4/4-SP-ST	4	PWR plant-unique single-purpose shipping container
P-T-4/3-SP-ST	3	PWR Derated plant-unique single-purpose shipping container
P-T-4/4-SP-MOX	4	PWR Mixed-oxide single-purpose shipping container
P-T-4/4-SP-BP	1	PWR plant-unique single-purpose shipping container

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. BWR = boiling-water reactor; PWR = pressurized-water reactor; SNF = spent nuclear fuel.

exceeded the capabilities of one of the casks, the model reduced the cask's capacity for the affected shipments. The reduction, which is sometimes referred to as cask derating, was needed to satisfy nuclear criticality, shielding, and thermal constraints. For shipments that DOE would make using specific casks, derating would be accomplished by partially filling the assigned casks in compliance with provisions of applicable Nuclear Regulatory Commission certificates of compliance. An example of derating is discussed in Section 5 of the GA-4 legal-weight truck shipping cask design report (DIRS 101831-General Atomics 1993, p. 5.5-1). The analysis addresses transport of two high-burnup or short cooling time pressurized-water reactor assemblies rather than four design basis assemblies.

RAIL SHIPMENTS

This appendix assumes that rail shipments of spent nuclear fuel would use large rail shipping casks, one per railcar. DOE anticipates that as many as five railcars with casks containing spent nuclear fuel or high-level radioactive waste would move together in individual trains with buffer cars and escort cars. For general freight service, a train would include other railcars with other materials. In dedicated (or special) service, trains would move only railcars containing spent nuclear fuel or high-level radioactive waste and the buffer and escort cars.

For the mostly rail scenario, six sites without sufficient crane capacity to lift a rail cask or without other factors such as sufficient floor loading capacity or ceiling height were assumed to ship by legal-weight truck. However, the analysis assumed that these sites would be upgraded to handle rail casks once the reactors were shut down, and all remaining spent nuclear fuel would ship by rail. Of these six sites, two are direct rail and four are indirect rail sites. Of the four with indirect rail access, three have access to a navigable waterway. The 24 sites with sufficient crane capacity but without direct rail access were assumed to ship by heavy-haul truck to the nearest railhead. Of these 24 sites, 17 with access to navigable waterways were analyzed for shipping by barge to a railhead (see Section J.2.4). The number of rail shipments (direct or indirect) was estimated based on each site using the largest cask size feasible based on the load capacity of its cask handling crane. In calculating the number of shipments from the sites, the model used the *Acceptance, Priority Ranking & Annual Capacity Report* (DIRS 104382-DOE 1995, all). Using CALVIN, the number of shipments of legal-weight truck casks (Figure J-3) of commercial spent nuclear fuel estimated for the Proposed Action (63,000 MTHM of commercial spent nuclear fuel) for the mostly legal-weight truck scenario, would be about 15,000 containing boiling-water reactor assemblies and 26,000 containing pressurized-water reactor assemblies. Under Inventory Modules 1 and 2, for which approximately 105,000 MTHM of commercial spent nuclear fuel would be shipped to the repository (see Appendix A), the estimated number of shipments for the mostly legal-weight truck scenario would be 29,000 for boiling-water reactor spent nuclear fuel and 51,000 for pressurized-water reactor spent nuclear fuel. Table J-4 lists the number of shipments of commercial spent nuclear fuel for the mostly legal-weight truck scenario. Specifically, it lists the site, plant, and state where shipments would originate, the total number of shipments from each site, and the type of spent nuclear fuel that would be shipped. A total of 72 commercial sites with 104 plants (or facilities) are listed in the table.

The number of shipments of truck and rail casks (Figure J-4) of commercial spent nuclear fuel estimated for the Proposed Action for the mostly rail scenario would be approximately 2,700 for boiling-water reactor spent nuclear fuel and 5,600 for pressurized-water reactor spent nuclear fuel. Under Modules 1 and 2, the estimated number of shipments for the mostly rail scenario would be approximately 5,400 containing boiling-water reactor spent nuclear fuel and 10,700 containing pressurized-water reactor spent nuclear fuel. Table J-5 lists the number of shipments for the mostly rail scenario. It also lists the site and state where shipments would originate, the total number of shipments from each site, the size of rail cask assumed for each site, and the type of spent nuclear fuel that would be shipped. In addition, it lists the 24 sites not served by a railroad that would ship rail casks by barge or heavy-haul trucks to a nearby railhead and the 6 commercial sites without capability to load a rail cask.

J.1.2.1.2 *DOE Spent Nuclear Fuel and High-Level Radioactive Waste*

To estimate the number of DOE spent nuclear fuel and high-level radioactive waste shipments, the analysis used the number of handling units or number of canisters and the number of canisters per shipment reported by the DOE sites in 1998 (see Appendix A, p. A-34; DIRS 104778-Jensen 1998, all). To determine the number of shipments of DOE spent nuclear fuel and high-level radioactive waste, the analysis assumed one canister would be shipped in a legal-weight truck cask. For rail shipments, the analysis assumed that five 61-centimeter (24-inch)-diameter high-level radioactive waste canisters would be shipped in a rail cask. For rail shipments of DOE spent nuclear fuel, the analysis assumed that rail casks would contain nine approximately 46-centimeter (18-inch) canisters or four approximately 61-centimeter canisters. The number of DOE spent nuclear fuel canisters of each size is presented in Appendix A.

Under the mostly legal-weight truck scenario for the Proposed Action, DOE would transport a total of 11,785 truck shipments of DOE spent nuclear fuel and high-level radioactive waste (one high-level waste canister per shipment) to the repository. In addition, DOE would transport 300 shipments of naval spent nuclear fuel by rail from the Idaho National Engineering and Environmental Laboratory to the repository

Table J-4. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Browns Ferry	Browns Ferry 1	AL	B[b]	738	1,550
	Browns Ferry 3	AL	B	324	807
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	363	779
	Joseph M. Farley 2	AL	P	330	843
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	362	645
	Arkansas Nuclear One, Unit 2	AR	P	432	905
Palo Verde	Palo Verde 1	AZ	P	383	694
	Palo Verde 2	AZ	P	375	691
	Palo Verde 3	AZ	P	360	716
Diablo Canyon	Diablo Canyon 1	CA	P	359	971
	Diablo Canyon 2	CA	P	370	1,130
Humboldt Bay	Humboldt Bay	CA	B	44	44
Rancho Seco	Rancho Seco 1	CA	P	124	124
San Onofre	San Onofre 1	CA	P	52	52
	San Onofre 2	CA	P	408	817
	San Onofre 3	CA	P	393	829
Haddam Neck	Haddam Neck	CT	P	255	255
Millstone	Millstone 1	CT	B	321	321
	Millstone 2	CT	P	361	694
	Millstone 3	CT	P	310	1,008
Crystal River	Crystal River 3	FL	P	277	621
St. Lucie	St. Lucie 1	FL	P	426	849
	St. Lucie 2	FL	P	380	987
Turkey Point	Turkey Point 3	FL	P	291	574
	Turkey Point 4	FL	P	292	570
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	939	1,820
Vogtle	Vogtle 1	GA	P	725	1,379
Duane Arnold	Duane Arnold	IA	B	324	576
Braidwood	Braidwood 1	IL	P	565	1,142
Byron	Byron 1	IL	P	617	1,136
Clinton	Clinton 1	IL	B	363	636
Dresden/Morris	Dresden 1	IL	B	76	76
	Dresden 2	IL	B	459	726
	Dresden 3	IL	B	514	760
	Morris[d]	IL	B	319	319
	Morris[d]	IL	P	88	88
LaSalle	LaSalle 1	IL	B	769	2,080
Quad Cities	Quad Cities 1	IL	B	979	1,567
Zion	Zion 1	IL	P	557	557
Wolf Creek	Wolf Creek 1	KS	P	396	678
River Bend	River Bend 1	LA	B	353	636
Waterford	Waterford 3	LA	P	374	607
Pilgrim	Pilgrim 1	MA	B	322	575
Yankee-Rowe	Yankee-Rowe 1	MA	P	134	134
Calvert Cliffs	Calvert Cliffs 1	MD	P	867	1,612
Maine Yankee	Maine Yankee	ME	P	356	356
Big Rock Point	Big Rock Point	MI	B	110	111
D. C. Cook	D. C. Cook 1	MI	P	832	1,759
Fermi	Fermi 2	MI	B	377	662
Palisades	Palisades	MI	P	409	660
Monticello	Monticello	MN	B	257	435
Prairie Island	Prairie Island 1	MN	P	665	1,109
Callaway	Callaway 1	MO	P	435	701
Grand Gulf	Grand Gulf 1	MS	B	592	1,383
Brunswick	Brunswick 1	NC	P	40	40
	Brunswick 2	NC	P	36	36
	Brunswick 1	NC	B	281	702
	Brunswick 2	NC	B	282	657

Table J-4. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Shearon Harris	Shearon Harris 1	NC	P	289	549
	Shearon Harris	NC	B	152	152
McGuire	McGuire 1	NC	P	372	932
	McGuire 2	NC	P	419	1,069
Cooper Station	Cooper Station	NE	B	272	621
Fort Calhoun	Fort Calhoun	NE	P	260	457
Seabrook	Seabrook 1	NH	P	277	590
Oyster Creek	Oyster Creek 1	NJ	B	451	658
Salem/Hope Creek	Salem 1	NJ	P	329	725
	Salem 2	NJ	P	304	826
	Hope Creek	NJ	B	444	796
James A. FitzPatrick/ Nine Mile Point	James A. FitzPatrick	NY	B	413	732
	Nine Mile Point 1	NY	B	426	628
	Nine Mile Point 2	NY	B	387	722
Ginna	Ginna	NY	P	320	472
Indian Point	Indian Point 1	NY	P	40	40
	Indian Point 2	NY	P	400	805
	Indian Point 3	NY	P	285	694
Davis-Besse	Davis-Besse 1	OH	P	343	786
Perry	Perry 1	OH	B	293	528
Trojan	Trojan	OR	P	195	195
Beaver Valley	Beaver Valley 1	PA	P	309	649
	Beaver Valley 2	PA	P	248	472
Limerick	Limerick 1	PA	B	740	1,354
Peach Bottom	Peach Bottom 2	PA	B	567	1,023
	Peach Bottom 3	PA	B	575	1,035
Susquehanna	Susquehanna 1	PA	B	1,044	2,482
Three Mile Island	Three Mile Island 1	PA	P	320	654
Catawba	Catawba 1	SC	P	327	555
	Catawba 2	SC	P	310	574
Oconee	Oconee 1	SC	P	970	1,668
	Oconee 3	SC	P	324	666
H. B. Robinson	H. B. Robinson 2	SC	P	249	470
Summer	Summer 1	SC	P	281	713
Sequoyah	Sequoyah	TN	P	644	1,768
Watts Bar	Watts Bar 1	TN	P	158	552
Comanche Peak	Comanche Peak 1	TX	P	665	1,409
South Texas	South Texas 1	TX	P	271	614
	South Texas 2	TX	P	257	590
North Anna	North Anna 1	VA	P	675	1,588
Surry	Surry 1	VA	P	863	1,457
Vermont Yankee	Vermont Yankee 1	VT	B	380	613
Columbia Generating Station	Columbia Generating Station	WA	B	415	1,006
Kewaunee	Kewaunee	WI	P	306	516
LaCrosse	LaCrosse	WI	B	37	37
Point Beach	Point Beach	WI	P	653	1,051
Total BWR[b]				15,229	28,719
Total PWR[c]				25,772	50,965

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.

Table J-5. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Browns Ferry	Browns Ferry 1	AL	B[b]	Rail	122	247
	Browns Ferry 3	AL	B	Rail	51	120
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	Rail	57	132
	Joseph M. Farley 2	AL	P	Rail	53	131
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	Rail	57	108
	Arkansas Nuclear One, Unit 2	AR	P	Rail	64	149
Palo Verde	Palo Verde 1	AZ	P	Rail	65	97
	Palo Verde 2	AZ	P	Rail	62	94
	Palo Verde 3	AZ	P	Rail	66	102
Diablo Canyon	Diablo Canyon 1	CA	P	Rail	60	148
	Diablo Canyon 2	CA	P	Rail	61	160
Humboldt Bay	Humboldt Bay	CA	B	Rail	6	6
Rancho Seco	Rancho Seco 1	CA	P	Rail	21	21
San Onofre	San Onofre 1	CA	P	Rail	9	9
	San Onofre 2	CA	P	Rail	65	131
	San Onofre 3	CA	P	Rail	64	137
Haddam Neck	Haddam Neck	CT	P	Rail	40	40
Millstone	Millstone 1	CT	B	Rail	91	91
	Millstone 2	CT	P	Rail	115	199
	Millstone 3	CT	P	Rail	49	138
Crystal River	Crystal River 3	FL	P	Rail	25	17
Crystal River	Crystal River 3	FL	P	Truck	133	437
St Lucie	St. Lucie 1	FL	P	Rail	12	13
St. Lucie	St. Lucie 1	FL	P	Truck	358	751
	St. Lucie 2	FL	P	Rail	61	147
Turkey Point	Turkey Point 3	FL	P	Rail	52	85
	Turkey Point 4	FL	P	Rail	52	86
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	Rail	116	288
Vogtle	Vogtle 1	GA	P	Rail	205	283
Duane Arnold	Duane Arnold	IA	B	Rail	57	129
Braidwood	Braidwood 1	IL	P	Rail	94	162
Byron	Byron 1	IL	P	Rail	101	159
Clinton	Clinton 1	IL	B	Rail	59	87
Dresden/Morris	Dresden 1	IL	B	Rail	11	11
	Dresden 2	IL	B	Rail	83	158
	Dresden 3	IL	B	Rail	89	160
	Morris[d]	IL	B	Rail	43	43
	Morris[d]	IL	P	Rail	15	15
LaSalle	LaSalle 1	IL	B	Rail	101	305
Quad Cities	Quad Cities 1	IL	B	Rail	172	329
Zion	Zion 1	IL	P	Rail	93	93
Wolf Creek	Wolf Creek 1	KS	P	Rail	63	97
River Bend	River Bend 1	LA	B	Rail	57	87
Waterford	Waterford 3	LA	P	Rail	66	93
Pilgrim	Pilgrim 1	MA	B	Rail	24	18
Pilgrim	Pilgrim 1	MA	B	Truck	154	394
Yankee-Rowe	Yankee-Rowe 1	MA	P	Rail	15	15
Calvert Cliffs	Calvert Cliffs 1	MD	P	Rail	169	320
Maine Yankee	Maine Yankee	ME	P	Rail	55	55
Big Rock Point	Big Rock Point	MI	B	Rail	7	7
D. C. Cook	D. C. Cook 1	MI	P	Rail	149	268
Fermi	Fermi 2	MI	B	Rail	61	91
Palisades	Palisades	MI	P	Rail	70	122
Monticello	Monticello	MN	B	Rail	32	19
Monticello	Monticello	MN	B	Truck	8	250
Prairie Island	Prairie Island 1	MN	P	Rail	103	205
Callaway	Callaway 1	MO	P	Rail	71	101
Grand Gulf	Grand Gulf 1	MS	B	Rail	80	215

Table J-5. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Brunswick	Brunswick 1	NC	P[c]	Rail	14	14
	Brunswick 2	NC	P	Rail	12	12
	Brunswick 1	NC	B[b]	Rail	78	142
	Brunswick 2	NC	B	Rail	78	140
Shearon Harris	Shearon Harris 1	NC	P	Rail	89	146
	Shearon Harris	NC	B	Rail	43	43
McGuire	McGuire 1	NC	P	Rail	83	164
	McGuire 2	NC	P	Rail	89	173
Cooper Station	Cooper Station	NE	B	Rail	42	124
Fort Calhoun	Fort Calhoun	NE	P	Rail	61	120
Seabrook	Seabrook 1	NH	P	Rail	49	80
Oyster Creek	Oyster Creek 1	NJ	B	Rail	64	110
Salem/Hope Creek	Salem 1	NJ	P	Rail	59	101
	Salem 2	NJ	P	Rail	54	108
	Hope Creek	NJ	B	Rail	67	105
James A. FitzPatrick/	FitzPatrick	NY	B	Rail	60	121
Nine Mile Point	Nine Mile Point 1	NY	B	Rail	72	99
	Nine Mile Point 2	NY	B	Rail	65	105
Ginna	Ginna	NY	P	Rail	36	22
Ginna	Ginna	NY	P	Truck	91	297
Indian Point	Indian Point 1	NY	P	Truck	40	40
	Indian Point 2	NY	P	Rail	35	34
	Indian Point 2	NY	P	Truck	150	471
	Indian Point 3	NY	P	Rail	22	19
	Indian Point 3	NY	P	Truck	145	482
Davis-Besse	Davis-Besse 1	OH	P	Rail	64	140
Perry	Perry 1	OH	B	Rail	42	67
Trojan	Trojan	OR	P	Rail	33	33
Beaver Valley	Beaver Valley 1	PA	P	Rail	52	94
	Beaver Valley 2	PA	P	Rail	41	76
Limerick	Limerick 1	PA	B	Rail	148	216
Peach Bottom	Peach Bottom 2	PA	B	Rail	82	157
	Peach Bottom 3	PA	B	Rail	80	157
Susquehanna	Susquehanna 1	PA	B	Rail	201	460
Three Mile Island	Three Mile Island 1	PA	P	Rail	57	97
Catawba	Catawba 1	SC	P	Rail	70	109
	Catawba 2	SC	P	Rail	69	107
Oconee	Oconee 1	SC	P	Rail	208	353
	Oconee 3	SC	P	Rail	64	129
H. B. Robinson	H. B. Robinson 2	SC	P	Rail	82	128
Summer	Summer 1	SC	P	Rail	46	113
Sequoyah	Sequoyah	TN	P	Rail	95	275
Watts Bar	Watts Bar 1	TN	P	Rail	26	74
Comanche Peak	Comanche Peak 1	TX	P	Rail	154	250
South Texas	South Texas 1	TX	P	Rail	58	104
	South Texas 2	TX	P	Rail	57	105
North Anna	North Anna 1	VA	P	Rail	143	289
Surry	Surry 1	VA	P	Rail	197	330
Vermont Yankee	Vermont Yankee 1	VT	B	Rail	73	137
Columbia Generating Station	Columbia Generating Station	WA	B	Rail	77	159
Kewaunee	Kewaunee	WI	P	Rail	51	87
La Crosse	La Crosse	WI	B	Rail	5	5
Point Beach	Point Beach	WI	P	Rail	130	213
Total BWR[b]					2,701	5,402
Total PWR[c]					5,596	10,709

a. Source: DIRS 157206-CRWMS M&O (2000, all).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.

(one naval spent nuclear fuel canister per rail cask). For Modules 1 and 2 under the mostly legal-weight truck scenario, the analysis estimated 26,001 DOE spent nuclear fuel and high-level radioactive waste truck shipments, as well as the 300 naval spent nuclear fuel shipments by rail.

Under the mostly rail scenario for the Proposed Action, the analysis estimated that DOE would transport 2,128 railcar shipments of DOE spent nuclear fuel and high-level radioactive waste (five high-level waste canisters per shipment), as well as the 300 shipments of naval spent nuclear fuel. For Modules 1 and 2 under this scenario, DOE would transport 4,954 railcar shipments of DOE spent nuclear fuel and high-level radioactive waste, as well as the 300 shipments of naval spent nuclear fuel. Table J-6 lists the estimated number of shipments of DOE and naval spent nuclear fuel from each of the sites for both the Proposed Action and Modules 1 and 2. Table J-7 lists the number of shipments of high-level radioactive waste for the Proposed Action and for Modules 1 and 2.

Table J-6. DOE and naval spent nuclear fuel shipments by site.

	Proposed Action		Module 1 or 2	
Site	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a]	1,388[b]	433	1,467[c]	442
Savannah River Site	1,316	149	1,411	159
Hanford	754	147	809	157
Fort St. Vrain	312	36	334	38
Totals	***3,770***	***765***	***4,021***	***796***

a. INEEL = Idaho National Engineering and Environmental Laboratory.
b. Includes 1,088 truck shipments of DOE spent nuclear fuel and 300 railcar shipments of naval spent nuclear fuel.
c. Includes 1,167 truck shipments of DOE spent nuclear fuel and 300 railcar shipments of naval spent nuclear fuel.

Table J-7. High-level radioactive waste shipments by site.[a]

	Proposed Action		Module 1 or 2	
Site	Mostly truck[b]	Mostly rail[c]	Mostly truck[b]	Mostly rail[c]
INEEL[d]	0	0	1,292	260[e]
Hanford	1,960	392	14,500	2,900
Savannah River Site	6,055	1,211	6,188	1,238
West Valley[f]	300	60	300	60
Totals	***8,315***	***1,663***	***22,280***	***4,458***

a. The total U.S. inventory of high-level radioactive waste at the time of shipment would be 22,280 canisters. Under the Proposed Action, DOE would only ship 8,315 canisters. Under Inventory Module 1 or 2, DOE would ship the entire inventory.
b. One canister per shipment.
c. Five canisters per shipment.
d. INEEL = Idaho National Engineering and Environmental Laboratory.
e. 238 shipments of Idaho Nuclear Technology and Engineering Center glass form waste, 20 shipments of Argonne National Laboratory-West ceramic form waste, and 2 shipments of Argonne National Laboratory-West metallic form waste (see Appendix A, Section A.2.3.5.1).
f. High-level radioactive waste at West Valley is commercial rather than DOE waste.

J.1.2.1.3 *Greater-Than-Class-C and Special-Performance-Assessment-Required Waste Shipments*

Reasonably foreseeable future actions could include shipment of Greater-Than-Class-C and Special-Performance-Assessment-Required waste to the Yucca Mountain Repository (Appendix A describes Greater-Than-Class-C and Special-Performance-Assessment-Required wastes). Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate low-level radioactive waste that exceeds the Nuclear Regulatory Commission Class C shallow-land-burial disposal limits. In addition to DOE-held material, there are three other sources or categories of Greater-Than-Class-C low-level radioactive waste:

- Nuclear utilities
- Sealed sources
- Other generators

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C low-level radioactive waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

The analysis estimated the number of shipments of Greater-Than-Class-C and Special-Performance-Assessment-Required waste by assuming that 10 cubic meters (about 350 cubic feet) would be shipped in a rail cask and 2 cubic meters (about 71 cubic feet) would be shipped in a truck cask. Table J-8 lists the resulting number of commercial Greater-Than-Class-C shipments in Inventory Module 2 for both truck and rail shipments. The shipments of Greater-Than-Class-C waste from commercial utilities would originate among the commercial reactor sites. Typically, boiling-water reactors would ship a total of about 9 cubic meters (about 318 cubic feet) of Greater-Than-Class-C waste per site, while pressurized-water reactors would ship about 20 cubic meters (about 710 cubic feet) per site (see Appendix A). The impacts of transporting this waste were examined for each reactor site. The analysis assumed that sealed sources and Greater-Than-Class-C waste identified as "other" would be shipped from the DOE Savannah River Site (see Table J-8).

Table J-8. Commercial Greater-Than-Class-C waste shipments.[a]

Category	Truck	Rail
Commercial utilities	742	210
Sealed sources	121	25
Other	233	47
Totals	***1,096***	***282***

a. Source: Appendix A.

The analysis assumed DOE Special-Performance-Assessment-Required waste would be shipped from four DOE sites listed in Table J-9. Naval reactor and Argonne East Special-Performance-Assessment-Required waste is assumed to be shipped from the Idaho National Engineering and Environmental Laboratory.

Table J-9. DOE Special-Performance-Assessment-Required waste shipments.[a]

Site[b]	Rail	Truck
Hanford	2	10
INEEL[c]	58	66
SRS (ORNL)	294	1,466
West Valley	56	276
Totals	***410***	***1,763***

a. Source: Appendix A; rounded.
b. Abbreviations: INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; ORNL = Oak Ridge National Laboratory.
c. Includes 55 rail shipments of naval Special-Performance-Assessment-Required waste. These shipments would travel by rail regardless of scenario.

J.1.2.1.4 *Sensitivity of Transportation Impacts to Number of Shipments*

As discussed in Section J.1.2.1, the number of shipments from commercial and DOE sites to the repository would depend on the mix of legal-weight truck and rail shipments. At this time, many years before shipments could begin, it is impossible to predict the mix with a reasonable degree of accuracy. Therefore, the analysis used two scenarios to provide results that bound the range of anticipated impacts. Thus, for a mix of legal-weight truck and rail shipments within the range of the mostly legal-weight truck and mostly rail scenarios, the impacts would be likely to lie within the bounds of the impacts predicted by the analysis. For example, a mix that is different from the scenarios analyzed could consist of 10,000 legal-weight truck shipments and 8,000 rail shipments over 24 years (compared to approximately 1,100 and 9,600, respectively, for the mostly rail scenario). In this example, the number of traffic fatalities would be between 3.1 (estimated for the Proposed Action under the mostly rail scenario) and 4.5 (estimated for the mostly legal-weight truck scenario). Other examples that have different mixes within the ranges bounded by the scenarios would lead to results that would be within the range of the evaluated impacts.

In addition to mixes within the brackets, the number of shipments could fall outside the ranges used for the mostly legal-weight truck and rail transportation scenarios. If, for example, the mostly rail scenario used smaller rail casks than the analysis assumed, the number of shipments would be greater. If spent nuclear fuel was placed in the canisters before they were shipped, the added weight and size of the canisters would reduce the number of fuel assemblies that a given cask could accommodate; this would increase the number of shipments. However, for the mostly rail scenario, even if the capacity of the casks was half that used in the analysis, the impacts would remain below those forecast for the mostly legal-weight truck scenario. Although impacts would be related to the number of shipments, because the number of rail shipments would be very small in comparison to the total railcar traffic on the Nation's railroads, increases or decreases would be small for impacts to biological resources, air quality, hydrology, noise, and other environmental resource areas. Thus, the impacts of using smaller rail casks would be covered by the values estimated in this EIS.

For legal-weight truck shipments, the use of casks carrying smaller payloads than those used in the analysis (assuming the shipment of the same spent nuclear fuel) would lead to larger impacts for incident-free transportation and traffic fatalities and about the same level of radiological accident risk. The relationship is approximately linear; if the payloads of truck shipping casks in the mostly legal-weight truck scenario were less by one-half, the incident-free impacts would increase by approximately a factor of 2. Conversely, because the amount of radioactive material in a cask would be less (assuming shipment of the same spent nuclear fuel), the radiological consequences of maximum reasonably foreseeable accident scenarios would be less with the use of smaller casks. If smaller casks were used to accommodate shipments of spent nuclear fuel with shorter cooling time and higher burnup, the radiological consequences of maximum reasonably foreseeable accident scenarios would be about the same.

J.1.2.2 Transportation Routes

At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Nonetheless, this analysis used current regulations governing highway shipments and historic rail industry practices to select existing highway and rail routes to estimate potential environmental impacts of national transportation. Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with applicable regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission in effect at the time the shipments occurred, as stated in the proposed DOE revised policy and procedures (DIRS 104741-DOE 1998, all) for implementing Section 180(c) of the Nuclear Waste Policy Act, as amended (NWPA).

Approximately 4 years before shipments to the proposed repository began, the Office of Civilian Radioactive Waste Management plans to identify the preliminary routes that DOE anticipates using in state and tribal jurisdictions so it can notify governors and tribal leaders of their eligibility for assistance under the provisions of Section 180(c) of the NWPA. DOE has published a revised proposed policy statement that sets forth its revised plan for implementing a program of technical and financial assistance to states and Native American tribes for training public safety officials of appropriate units of local government and tribes through whose jurisdictions the Department plans to transport spent nuclear fuel or high-level radioactive waste (63 *FR* 23756, January 2, 1998) (see Appendix M, Section M.8).

The analysis of impacts of the Proposed Action and Modules 1 and 2 used characteristics of routes that shipments of spent nuclear fuel and high-level radioactive waste could travel from the originating sites listed in Tables J-4 through J-7. Existing routes that could be used were identified for the mostly legal-weight truck and mostly rail transportation scenarios and included the 10 rail and heavy-haul truck implementing alternatives evaluated in the EIS for transportation in Nevada. The route characteristics used were the transportation mode (highway, railroad, or navigable waterway) and, for each of the modes, the total distance between an originating site and the repository. In addition, the analysis estimated the fraction of travel that would occur in rural, suburban, and urban areas for each route. The fraction of travel in each population zone was determined using 1990 Census data (see Section J.1.1.2 and J.1.1.3) to identify population-zone impacts for route segments. The highway routes were selected for the analysis using the HIGHWAY computer program and routing requirements of the U.S. Department of Transportation for shipments of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101). Shipments of spent nuclear fuel and high-level radioactive waste would contain Highway Route-Controlled Quantities of Radioactive Materials.

J.1.2.2.1 *Routes Used in the Analysis*

Routes used in the analysis of transportation impacts of the Proposed Action and Inventory Modules 1 and 2 are highways and rail lines that DOE anticipates it could use for legal-weight truck or rail shipments from each origin to Nevada. For rail shipments that would originate at sites not served by railroads, routes used for analysis include highway routes for heavy-haul trucks or barge routes from the sites to railheads. Figures J-5 and J-6 show the truck and rail routes, respectively, analyzed for the Proposed Action and Inventory Modules 1 and 2. Tables J-10 and J-11 list the lengths of trips and the distances of the highway and rail routes, respectively, in rural, suburban, and urban population zones. Sites that would be capable of loading rail casks, but that do not have direct rail access, are listed in Table J-11. The analysis used six ending rail nodes in Nevada (Beowawe, Caliente, Dry Lake, Eccles,

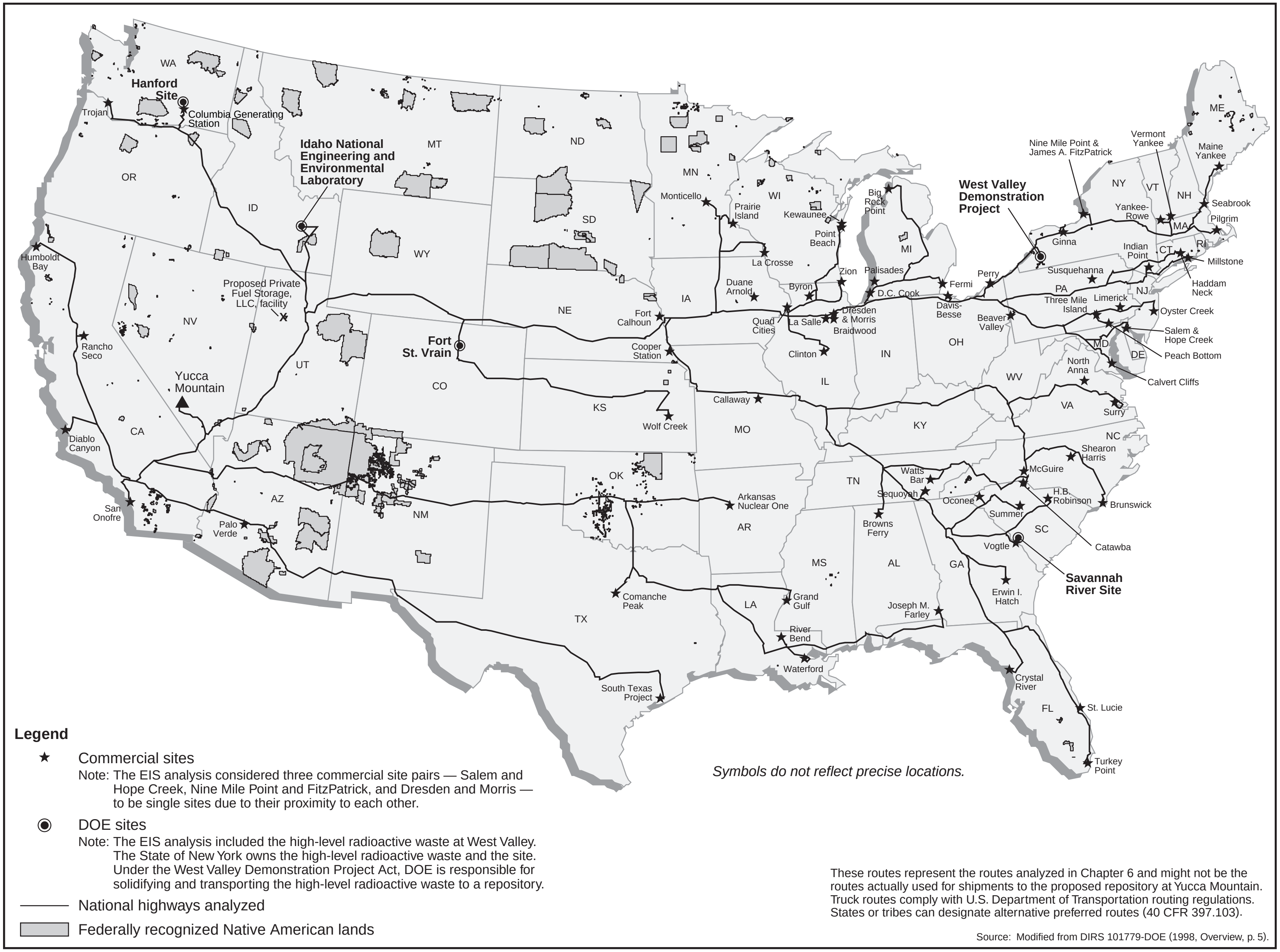


Figure J-5. Representative truck routes from commercial and DOE sites to Yucca Mountain analyzed for the Proposed Action and Inventory Modules 1 and 2.

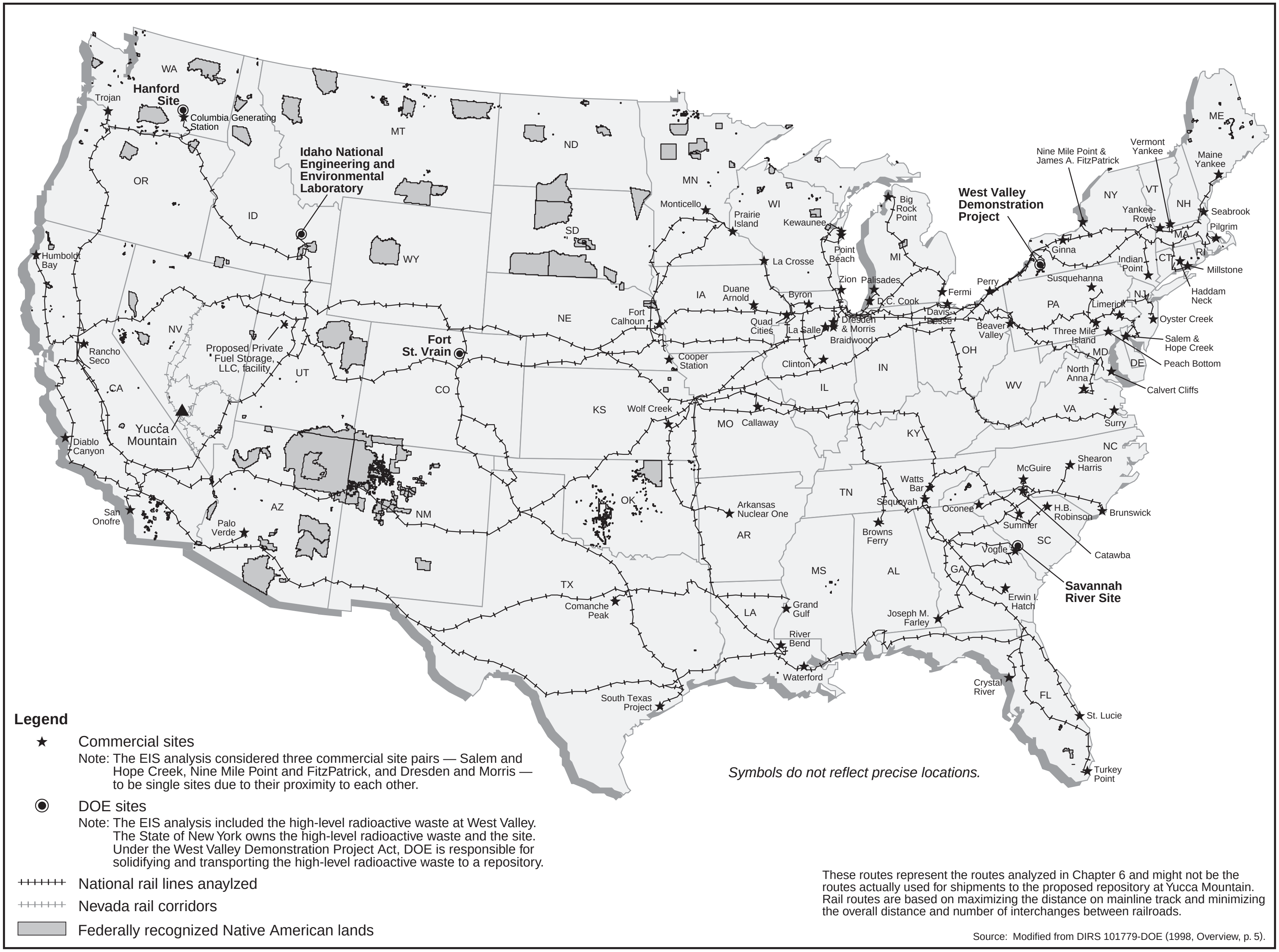


Figure J-6. Representative rail routes from commercial and DOE sites to Yucca Mountain analyzed for the Proposed Action and Inventory Modules 1 and 2.

Table J-10. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 1 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Browns Ferry	AL	3,798	3,344	393	61
Joseph M. Farley	AL	4,149	3,617	463	69
Arkansas Nuclear One	AR	2,810	2,588	191	30
Palo Verde	AZ	1,007	886	100	21
Diablo Canyon	CA	1,015	828	119	68
Humboldt Bay	CA	1,749	1,465	192	92
Rancho Seco	CA	1,228	1,028	124	76
San Onofre	CA	694	517	89	87
Haddam Neck	CT	4,519	3,708	736	75
Millstone	CT	4,527	3,673	746	109
Crystal River	FL	4,675	3,928	672	75
St. Lucie	FL	4,944	4,115	748	80
Turkey Point	FL	5,198	4,210	840	148
Edwin I. Hatch	GA	4,342	3,695	572	74
Vogtle	GA	4,294	3,623	592	79
Duane Arnold	IA	2,773	2,544	189	40
Braidwood	IL	3,063	2,796	231	36
Byron	IL	3,032	2,773	223	36
Clinton	IL	3,104	2,814	252	38
Dresden/Morris	IL	3,059	2,798	225	36
La Salle	IL	3,017	2,766	215	36
Quad Cities	IL	2,877	2,631	211	36
Zion	IL	3,167	2,834	284	50
Wolf Creek	KS	2,686	2,474	173	38
River Bend	LA	3,479	3,097	322	60
Waterford	LA	3,565	3,159	346	59
Pilgrim	MA	4,722	3,697	930	94
Yankee-Rowe	MA	4,615	3,692	831	92
Calvert Cliffs	MD	4,278	3,511	684	82
Maine Yankee	ME	4,894	3,733	1,052	108
Big Rock Point	MI	3,866	3,266	547	52
D. C. Cook	MI	3,196	2,827	318	51
Fermi	MI	3,524	3,014	449	61
Palisades	MI	3,244	2,855	338	51
Monticello	MN	3,003	2,702	261	41
Prairie Island	MN	2,993	2,720	232	41
Callaway	MO	2,988	2,721	225	43
Grand Gulf	MS	3,354	2,989	311	54
Brunswick	NC	4,773	3,994	696	82
Shearon Harris	NC	4,543	3,815	649	79
McGuire	NC	4,347	3,737	535	74
Cooper Station	NE	2,523	2,328	160	36
Fort Calhoun	NE	2,348	2,165	148	35
Seabrook	NH	4,725	3,675	942	107
Oyster Creek	NJ	4,424	3,530	825	69
Salem/Hope Creek	NJ	4,350	3,531	739	79
Ginna	NY	4,089	3,356	642	91
Indian Point	NY	4,382	3,695	620	67
James A. FitzPatrick/ Nine Mile Point	NY	4,234	3,461	688	85

Table J-10. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 2 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Davis-Besse	OH	3,520	3,106	358	55
Perry	OH	3,693	3,157	464	73
Trojan	OR	2,137	1,865	236	36
Beaver Valley	PA	3,779	3,214	500	64
Limerick	PA	4,287	3,484	741	62
Peach Bottom	PA	4,205	3,479	662	63
Susquehanna	PA	4,126	3,539	528	59
Three Mile Island	PA	4,147	3,443	643	60
Catawba	SC	4,350	3,686	594	70
Oconee	SC	4,208	3,586	551	71
H. B. Robinson	SC	4,467	3,739	647	81
Summer	SC	4,352	3,704	576	71
Sequoyah	TN	3,856	3,361	433	61
Watts Bar	TN	3,933	3,460	413	61
Comanche Peak	TX	2,794	2,547	213	34
South Texas	TX	3,011	2,652	295	64
North Anna	VA	4,437	3,825	533	79
Surry	VA	4,611	3,898	629	83
Vermont Yankee	VT	4,615	3,675	846	94
Colombia Generating Station	WA	1,880	1,669	178	32
Kewaunee	WI	3,347	2,978	314	55
La Crosse	WI	3,014	2,773	198	43
Point Beach	WI	3,341	2,972	314	55
Ft. St. Vrain[d]	CO	1,637	1,501	108	28
INEEL[e]	ID	1,201	1,044	129	27
West Valley[f]	NY	3,959	3,322	562	75
Savannah River[e]	SC	4,294	3,622	593	79
Hanford[e]	WA	1,881	1,671	178	32

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances determined for purposes of analysis using HIGHWAY computer program.
c. Totals might differ from sums due to method of calculation and rounding.
d. DOE spent nuclear fuel site.
e. DOE spent nuclear fuel and high-level radioactive waste site.
f. High-level radioactive waste site.

Jean, and Apex) to select rail routes from the 77 sites. These rail nodes would be starting points for the rail and heavy-haul truck implementing alternatives analyzed for transportation in Nevada.

Selection of Highway Routes. The analysis of national transportation impacts used route characteristics of existing highways, such as distances, population densities, and state-level accident statistics. The analysis of highway shipments of spent nuclear fuel and high-level radioactive waste used the HIGHWAY computer model (DIRS 104780-Johnson et al. 1993, all) to determine highway routes using regulations of the U.S. Department of Transportation (49 CFR 397.101) that specify how routes are selected. The selection of "preferred routes" is required for shipment of these materials. DOE has determined that the HIGHWAY program is appropriate for calculating highway routes and related information (DIRS 101845-Maheras and Pippen 1995, pp. 2 to 5). HIGHWAY is a routing tool that DOE has used in previous EISs [for example, the programmatic EIS on spent nuclear fuel (DIRS 101802-DOE 1995, Volume 1, p. I-6) and the Waste Isolation Pilot Plant Supplement II EIS (DIRS 101814-DOE 1997, pp. 5 to 13)] to determine highway routes for impact analysis.

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 1 of 3).

Site	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access				
Arkansas Nuclear One	2,593 - 2,930	2,427 - 2,720	149 - 181	17 - 29
Beaver Valley	3,242 - 3,579	2,675 - 2,968	452 - 484	115 - 127
Braidwood	2,586 - 2,923	2,260 - 2,553	253 - 286	73 - 85
Brunswick	4,145 - 4,482	3,363 - 3,656	721 - 753	60 - 72
Byron	2,403 - 2,740	2,207 - 2,500	172 - 204	24 - 35
Catawba	3,819 - 4,156	3,265 - 3,559	495 - 527	59 - 70
Clinton	2,595 - 2,932	2,358 - 2,651	196 - 228	41 - 53
Columbia Generating Station	1,369 - 1,706	1,274 - 1,567	84 - 116	11 - 22
Comanche Peak	2,492 - 2,678	2,218 - 2,401	213 - 236	37 - 43
Crystal River	4,175 - 4,653	3,481 - 3,960	587 - 672	55 - 106
D. C. Cook	2,632 - 2,969	2,261 - 2,555	277 - 309	94 - 105
Davis Besse	2,917 - 3,254	2,452 - 2,745	356 - 389	109 - 121
Dresden/Morris	2,510 - 2,847	2,253 - 2,546	222 - 255	35 - 46
Duane Arnold	2,168 - 2,505	2,014 - 2,307	135 - 167	20 - 31
Edwin I. Hatch	3,929 - 4,266	3,396 - 3,689	480 - 513	53 - 64
Fermi	3,072 - 3,409	2,513 - 2,806	437 - 469	123 - 135
H. B. Robinson	3,889 - 4,226	3,137 - 3,430	685 - 717	68 - 79
Humboldt Bay	724 - 1,412	550 - 1,093	137 - 239	36 - 80
James A. FitzPatrick/Nine Mile Point	3,632 - 3,969	2,848 - 3,141	631 - 663	154 - 165
Joseph M. Farley	4,021 - 4,358	3,438 - 3,731	529 - 561	54 - 66
La Crosse	2,851 - 3,579	2,578 - 3,361	196 - 234	22 - 39
La Salle	2,653 - 3,381	2,396 - 3,179	181 - 220	20 - 37
Limerick	3,934 - 4,271	3,148 - 3,441	664 - 696	123 - 135
Maine Yankee	4,435 - 4,771	3,245 - 3,538	1,008 - 1,040	182 - 193
McGuire	3,916 - 4,253	3,170 - 3,463	679 - 712	66 - 78
Millstone	4,139 - 4,476	3,078 - 3,371	893 - 925	168 - 179
Monticello	2,655 - 2,822	2,347 - 2,543	241 - 265	38 - 44
North Anna	3,944 - 4,281	3,132 - 3,425	639 - 672	172 - 184
Palo Verde	872 - 1,466	778 - 1,113	77 - 252	18 - 101
Perry	3,222 - 3,558	2,836 - 3,129	317 - 349	69 - 80
Prairie Island	2,344 - 2,681	2,100 - 2,393	223 - 255	22 - 33
Quad Cities	2,595 - 3,323	2,324 - 3,108	194 - 233	21 - 38
Rancho Seco	263 - 882	178 - 694	61 - 139	24 - 48
River Bend	3,266 - 3,405	2,966 - 3,027	268 - 358	28 - 68
San Onofre	472 - 1,133	322 - 756	93 - 264	58 - 112
Seabrook	4,282 - 4,619	3,183 - 3,477	920 - 952	179 - 190
Sequoyah	3,366 - 3,703	3,044 - 3,337	277 - 309	46 - 57
Shearon Harris	4,046 - 4,383	3,301 - 3,595	686 - 718	59 - 70
South Texas	2,815 - 3,277	2,539 - 2,770	234 - 434	42 - 73
Summer	3,755 - 4,092	3,291 - 3,584	414 - 446	50 - 62
Susquehanna	3,827 - 4,164	2,883 - 3,176	771 - 803	173 - 185
Three Mile Island	3,828 - 4,165	3,129 - 3,422	588 - 620	111 - 123
Trojan	1,326 - 2,048	1,040 - 1,836	172 - 346	40 - 108
Vermont Yankee	4,078 - 4,415	3,135 - 3,429	778 - 811	164 - 176
Vogtle	3,985 - 4,322	3,443 - 3,736	489 - 522	53 - 64
Waterford	3,408 - 3,540	2,878 - 3,086	293 - 453	63 - 76
Watts Bar	3,310 - 3,647	3,011 - 3,304	254 - 286	46 - 57
Wolf Creek	2,108 - 2,445	1,995 - 2,288	98 - 130	15 - 27
Zion	2,542 - 2,879	2,231 - 2,525	247 - 279	64 - 75

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 2 of 3).

Site	Total[d]	Rural	Suburban	Urban
Commercial sites with indirect rail access				
Big Rock Point				
HH[e]-20.0 kilometers	3,258 - 3,595	2,766 - 3,059	399 - 431	93 - 105
Browns Ferry				
HH-55.4 kilometers	3,118 - 3,455	2,723 - 3,016	353 - 386	42 - 53
Callaway				
HH-18.5 kilometers	2,230 - 2,567	2,103 - 2,396	108 - 140	20 - 32
Calvert Cliffs				
HH-41.9 kilometers	3,829 - 4,166	3,024 - 3,317	631 - 663	174 - 185
Cooper Station				
HH-53.8 kilometers	1,852 - 2,189	1,719 - 2,012	109 - 141	25 - 36
Diablo Canyon				
HH-43.5 kilometers	715 - 789	461 - 522	162 - 181	73 - 105
Fort Calhoun				
HH-6.0 kilometers	1,736 - 2,073	1,656 - 1,949	70 - 102	10 - 21
Ginna				
HH-35.1 kilometers	3,532 - 3,869	2,792 - 3,086	604 - 636	136 - 147
Grand Gulf				
HH-47.8 kilometers	3,108 - 3,445	2,817 - 3,115	259 - 373	28 - 67
Haddam Neck				
HH-16.6 kilometers	4,105 - 4,442	3,070 - 3,363	868 - 901	167 - 178
Hope Creek				
HH-51.0 kilometers	3,978 - 4,315	2,842 - 3,135	912 - 944	225 - 236
Indian Point				
HH-14.2 kilometers	3,981 - 4,318	3,034 - 3,327	781 - 813	166 - 177
Kewanee				
HH-9.7 kilometers	2,867 - 3,204	2,421 - 2,714	363 - 395	84 - 95
Oconee				
HH-17.5 kilometers	3,738 - 4,075	3,221 - 3,514	464 - 496	54 - 65
Oyster Creek				
HH-28.5 kilometers	4,061 - 4,398	2,862 - 3,155	957 - 989	242 - 254
Palisades				
HH-41.9 kilometers	2,680 - 3,017	2,279 - 2,572	306 - 338	96 - 107
Peach Bottom				
HH-58.9 kilometers	3,849 - 4,186	3,134 - 3,427	604 - 637	111 - 122
Pilgrim				
HH-8.7 kilometers	4,263 - 4,600	3,103 - 3,396	986 - 1,018	174 - 185
Point Beach				
HH-36.4 kilometers	2,820 - 3,157	2,405 - 2,698	338 - 370	78 - 89
Salem				
HH-51.0 kilometers	3,950 - 4,287	2,868 - 3,161	864 - 896	219 - 230
St. Lucie				
HH-23.5 kilometers	4,315 - 4,840	3,464 - 3,984	732 - 809	74 - 125
Surry				
HH-75.2 kilometers	4,065 - 4,402	3,468 - 3,761	523 - 555	74 - 85
Turkey Point				
HH-17.4 kilometers	4,662 - 5,140	3,696 - 4,175	785 - 870	127 - 179
Yankee-Rowe				
HH-10.1 kilometers	3,998 - 4,335	3,083 - 3,376	752 - 784	164 - 175

Table J-11. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 3 of 3).

Site	Total[d]	Rural	Suburban	Urban
DOE spent nuclear fuel and high-level radioactive waste				
Ft. St. Vrain[f]	1,039 - 1,321	1,011 - 1,214	24 - 93	3 - 13
Hanford Site[g]	1,356 - 1,693	1,262 - 1,555	84 - 116	11 - 22
INEEL[g]	482 - 819	445 - 738	34 - 66	4 - 15
Savannah River Site[g]	3,751 - 4,088	3,081 - 3,374	605 - 638	65 - 76
West Valley[h]	3,447 - 3,784	2,774 - 3,067	538 - 570	135 - 146

a. The ending rail nodes (INTERLINE computer program designations) are Apex-14763; Caliente-14770; Beowawe-14791; and Jean-16328.
b. To convert kilometers to miles, multiply by 0.62137.
c. This analysis used the INTERLINE computer program to estimate distances.
d. Totals might differ from sums due to method of calculation and rounding.
e. HH = heavy-haul truck distance.
f. DOE spent nuclear fuel.
g. DOE spent nuclear fuel and high-level radioactive waste.
h. High-level radioactive waste.

Because the regulations require that the preferred routes result in reduced time in transit, changing conditions, weather, and other factors could result in the use of more than one route at different times for shipments between the same origin and destination. However, for this analysis the program selected only one route for travel from each site to the Yucca Mountain site. Section J.4 describes the highway routes used in the analysis along with estimated impacts of legal-weight truck shipments for each state.

Although shipments could use more than one preferred route in national highway transportation to comply with U.S. Department of Transportation regulations (49 CFR 397.101), under current U.S. Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States or tribes can designate alternative or additional preferred routes for highway shipments (49 CFR 397.103). At this time the State of Nevada has not identified any alternative or additional preferred routes that DOE could use for shipments to the repository.

STATE-DESIGNATED PREFERRED ROUTES

U.S. Department of Transportation regulations specify that states and tribes can designate preferred routes that are alternatives, or in addition to, Interstate System highways including bypasses or beltways for the transportation of Highway Route-Controlled Quantities of Radioactive Materials. Highway Route-Controlled of Radioactive Materials include spent nuclear fuel and high-level radioactive waste in quantities that would be shipped on a truck or railcar to the repository. If a state or tribe designated such a route, highway shipments of spent nuclear fuel and high-level radioactive waste would use the preferred route if (1) it was an alternative preferred route, (2) it would result in reduced time in transit, or (3) it would replace pickup or delivery routes. Fourteen states have designated alternative or additional preferred routes (65 *FR* 75771; December 4, 2000). Although Nevada has designated a State routing agency to the Department of Transportation (Nevada Revised Statutes, Chapter 408.141), the State has not yet designated alternative or preferred routes for Highway Route-Controlled Quantities of Radioactive Materials. State route designations in the future could require changes in highway routes that would be used for shipments of spent nuclear fuel and high-level radioactive waste from 77 sites to Yucca Mountain. As an example of recent changes, two states notified the U.S. Department of Transportation of state-designated preferred routes (65 *FR* 75771; December 4, 2000) near or following publication of the Draft EIS.

Selection of Rail Routes. Rail transportation routing of spent nuclear fuel and high-level radioactive waste shipments is not regulated by the U.S. Department of Transportation. As a consequence, the routing rules used by the INTERLINE computer program (DIRS 104781-Johnson et al. 1993, all) assumed that railroads would select routes using historic practices. DOE has determined that the INTERLINE program is appropriate for calculating routes and related information for use in transportation analyses (DIRS 101845-Maheras and Pippen 1995, pp. 2 to 5). Because the routing of rail shipments would be subject to future, possibly different practices of the involved railroads, DOE could use other rail routes. Section J.4 contains maps of the rail routes used in the analysis along with estimated impacts of rail shipments for each state.

For the 24 commercial sites that have the capability to handle and load rail casks but do not have direct rail service, DOE used the HIGHWAY computer program to identify routes for heavy-haul transportation to nearby railheads. For such routes, routing agencies in affected states would need to approve the transport and routing of overweight and overdimensional shipments.

J.1.2.2.2 *Routes for Shipping Rail Casks from Sites Not Served by a Railroad*

In addition to routes for legal-weight trucks and rail shipments, 24 commercial sites that are not served by a railroad, but that have the capability to load rail casks, could ship spent nuclear fuel to nearby railheads using heavy-haul trucks (see Table J-11). In addition, six of the sites that initially are legal-weight truck sites would be indirect rail sites after plant shutdown.

J.1.2.2.3 *Sensitivity of Analysis Results to Routing Assumptions*

Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission in effect at the time shipments would occur. Unless the State of Nevada designates alternative or additional preferred routes, to comply with U.S. Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments. At this time the State of Nevada has not identified any alternative or additional preferred routes DOE could use for shipments to the repository. Section J.3.1.3 examines the sensitivity of transportation impacts both nationally and regionally (within Nevada) to changes in routing assumptions within Nevada.

J.1.3 ANALYSIS OF IMPACTS FROM INCIDENT-FREE TRANSPORTATION

DOE analyzed the impacts of incident-free transportation for shipments of commercial and DOE spent nuclear fuel and DOE high-level radioactive waste that would be shipped under the Proposed Action and Inventory Modules 1 and 2 from 77 sites to the repository. The analysis estimated impacts to the public and workers and included impacts of loading shipping casks at commercial and DOE sites and other preparations for shipment as well as intermodal transfers of casks from heavy-haul trucks or barges to rail cars.

J.1.3.1 Methods and Approach for Analysis of Impacts for Loading Operations

The analysis used methods and assessments developed for spent nuclear fuel loading operations at commercial sites to estimate radiological impacts to involved workers at commercial and DOE sites. Previously developed conceptual radiation shield designs for shipping casks (DIRS 101747-Schneider et al. 1987, Sections 4 and 5), rail and truck shipping cask dimensions, and estimated radiation dose rates at locations where workers would load and prepare casks (DIRS 104791-DOE 1992, p. 4.2) for shipment were the analysis bases for loading operations. In addition, tasks and time-motion evaluations from these studies were used to describe spent nuclear fuel handling and loading. These earlier evaluations were

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The analysis assumed that noninvolved workers would not have tasks that would result in radiation exposure. In a similar manner, the analysis projected that the dose to the public from loading operations would be extremely small, resulting in no or small impacts. A separate evaluation of the potential radiation dose to members of the public from loading operations at commercial nuclear reactor facilities showed that the dose would be very low, less than 0.001 person-rem per metric ton uranium of spent nuclear fuel loaded (DIRS 104731-DOE 1986, p. 2.42, Figure 2.9). Public doses from activities at commercial and DOE sites generally come from exposure to airborne emissions and, in some cases, waterborne effluents containing low levels of radionuclides. However, direct radiation at publicly accessible locations near these sites typically is not measurable and contributes negligibly to public dose and radiological impacts. Though DOE expects no releases from loading operations, this analysis estimated that the dose to the public would be 0.001 person-rem per metric ton uranium, and metric ton equivalents, for DOE spent nuclear fuel and high-level radioactive waste. Noninvolved workers could also be exposed to low levels of radioactive materials and radioactivity from loadout operations. However, because these workers would not work in radiation areas they would receive a very small fraction of the dose received by involved workers. DOE anticipates that noninvolved workers would receive individual doses similar to those received by members of the public. Because the population of noninvolved workers would be small compared to the population of the general public near the 77 sites, the dose to these workers would be a small fraction of the public dose.

The analysis used several basic assumptions to evaluate impacts from loading operations at DOE sites:

- Operations to load spent nuclear fuel and high-level radioactive waste at DOE facilities would be similar to loading operations at commercial facilities.

- Commercial spent nuclear fuel would be in storage pools or in dry storage at the reactors and DOE spent nuclear fuel would be in dry storage, ready to be loaded directly in Nuclear Regulatory Commission-certified shipping casks and then on transportation vehicles. In addition, DOE high-level radioactive waste could be loaded directly in casks. All preparatory activities, including packaging, repackaging, and validating the acceptability of spent nuclear fuel for acceptance at the repository would be complete prior to loading operations.

- Commercial spent nuclear fuel to be placed in the shipping casks would be uncanistered or canistered fuel assemblies, with at least one assembly in a canister. DOE spent nuclear fuel and high-level radioactive waste would be in disposable canisters. Typically, uncanistered assemblies would be loaded into shipping casks under water in storage pools (wet storage). Canistered spent nuclear fuel could be loaded in casks directly from dry storage facilities or storage pools.

In addition, because handling and loading operations for DOE spent nuclear fuel and high-level radioactive waste and commercial spent nuclear fuel would be similar, the analysis assumed that impacts to workers during the loading of commercial spent nuclear fuel could represent those for the DOE materials, even though the radionuclide inventory of commercial fuel and the resultant external dose rate would be higher than those of the DOE materials. This conservative assumption of selecting impacts from commercial handling and loading operations overestimated the impacts of DOE loading operations, but it enabled the use of detailed real information developed for commercial loading operations to assess impacts for DOE operations. Equivalent information was not available for operations at DOE facilities. To gauge the conservatism of the assumption DOE compared the radioactivity of contents of shipments of commercial and DOE spent nuclear fuel and high-level radioactive waste. Table J-12 compares typical inventories of important contributors to the assessment of worker and public health impacts. These are cesium-137 and actinide isotopes (including plutonium) for rail shipments of commercial spent nuclear

Table J-12. Average cesium-137, actinide isotope, and total radioactive material content (curies) in a rail shipping cask.[a]

Material	Cesium-137	Actinides	Total (all isotopes)
Commercial spent nuclear fuel (PWR)[b]	816,000	694,000	2,130,000
High-level radioactive waste	27,000	53,000[c]	180,000
DOE spent nuclear fuel (except naval spent nuclear fuel)	119,000	40,000	265,000
Naval spent nuclear fuel	450,000	28,000	1,100,000

a. Source: Appendix A. Source estimated based on 24 typical pressurized-water reactor fuel assemblies for commercial spent nuclear fuel; one dual-purpose shipping canister for naval spent fuel; nine canisters of DOE spent nuclear fuel; and five canisters of high-level radioactive waste.

b. PWR = pressurized-water reactor.

c. Includes immobilized plutonium with high-level radioactive waste.

fuel, DOE spent nuclear fuel, and DOE high-level radioactive waste. Although other factors are also important (for example, material form and composition), these indicators provide an index of the relative hazard potential of the materials. Appendix A contains additional information on the radionuclide inventory and characteristics of spent nuclear fuel and high-level radioactive waste.

J.1.3.1.1 *Radiological Impacts of Loading Operations at Commercial Sites*

In 1987, DOE published a study of the estimated radiation doses to the public and workers resulting from the transport of spent nuclear fuel from commercial nuclear power reactors to a hypothetical deep geologic repository (DIRS 101747-Schneider et al. 1987, all). This study was based on a single set of spent nuclear fuel characteristics and a single split [30 percent/70 percent by weight; 900 metric tons uranium/2,100 metric tons uranium per year] between truck and rail conveyances. DOE published its findings on additional radiological impacts on monitored retrievable storage workers in an addendum to the 1987 report (DIRS 104791-DOE 1992, all). The technical approaches and impacts summarized in these DOE reports were used to project involved worker impacts that would result from commercial at-reactor spent nuclear fuel loading operations. DOE did not provide a separate analysis of noninvolved worker impacts in these reports. For the analysis in this EIS, DOE assumed that noninvolved workers would not receive radiation exposures from loading operations. This assumption is appropriate because noninvolved workers would be personnel with managerial or administrative support functions directly related to the loading tasks but at locations, typically in offices, away from areas where loading activities took place.

In the DOE study, worker impacts from loading operations were estimated for a light-water reactor with pool storage of spent nuclear fuel. The radiological characteristics of the spent nuclear fuel in the analysis was 10-year-old, pressurized-water reactor fuel with an exposure history (burnup) of 35,000 megawatt-days per metric ton. In addition, the reference pressurized-water reactor and boiling-water reactor fuel assemblies were assumed to contain 0.46 and 0.19 MTU, respectively, prior to reactor irradiation. The term MTU (metric ton of uranium) is from the DOE study. An MTU is approximately the same quantity of spent nuclear fuel as a metric ton of heavy metal, or MTHM, as described in this EIS. In this section, the terms are used interchangeably to allow the information reported in prior DOE studies to be used without modification. These parameters for spent nuclear fuel are similar to those presented in Appendix A of this EIS. The use of the parameters for spent nuclear fuel presented in Appendix A would be likely to lead to similar results.

In the 1987 study, radiation shielding analyses were done to provide information on (1) the conceptual configuration of postulated reference rail and truck transportation casks, and (2) the direct radiation levels at accessible locations near loaded transportation casks. The study also presented the results of a detailed time-motion analysis of work tasks that used a loading concept of operations. This task analysis was coupled with cask and at-reactor direct radiation exposure rates to estimate radiation doses to involved workers (that is, those who would participate directly in the handling and loading of the transportation casks and conveyances). Impacts to members of the public from loading operations had been shown to be small [fraction of a person-millirem population dose; (DIRS 101747-Schneider et al. 1987, p. 2.9)] and were eliminated from further analysis in the 1987 report. The at-reactor-loading concept of operations included the following activities:

1. Receiving the empty transportation cask at the site fence
2. Preparing and moving the cask into the facility loading area
3. Removing the cask from the site prime mover trailer
4. Preparing the cask for loading and placing it in the water-filled loading pit
5. Transferring spent nuclear fuel from its pool storage location to the cask
6. Removing the cask from the pool and preparing it for shipment
7. Placing the cask on the site prime mover trailer
8. Moving the loaded cask to the site fence where the trailer is connected to the transportation carrier's prime mover for offsite shipment

The results for loading operations are listed in Table J-13.

Table J-13. Principal logistics bases and results for the reference at-reactor loading operations.[a]

Parameter	Conveyance		
	Rail[b]	Truck[c]	Total
Annual loading rate (MTU/year)[d]	2,100	900	3,000
Transportation cask capacity, PWR - BWR (MTU/cask)	6.5 - 6.7	0.92 - 0.93	NA[e]
Annual shipment rate (shipments/year)	320	970	1,290
Average loading duration,[f] PWR - BWR (days)	2.3 - 2.5	1.3 - 1.4	NA
Involved worker specific CD,[g] PWR - BWR (person-rem/MTU)	0.06 - 0.077	0.29 - 0.31	NA

a. Source: DIRS 101747-Schneider et al. (1987, pp. 2.5 and 2.7).
b. 14 pressurized-water reactor and boiling-water reactor spent nuclear fuel assemblies per rail transportation cask.
c. 2 pressurized-water reactor and boiling-water reactor spent nuclear fuel assemblies per truck transportation cask.
d. MTU = metric tons of uranium. One MTU is approximately equal to 1 MTHM.
e. NA = not applicable.
f. Based on single shift operations; carrier drop-off and pick-up delays were not included.
g. Collective dose expressed as the sum of the doses accumulated by all loading (involved) workers, regardless of the total number of workers assigned to loading tasks.

The loading activities that the study determined would produce the highest collective unit impacts are listed in Table J-14. As listed in this table, the involved worker collective radiation doses would be dominated by tasks in which the workers would be near the transportation cask when it contained spent nuclear fuel, particularly when they were working around the cask lid area. These activities would deliver at least 40 percent of the total collective worker doses. Worker impacts from the next largest dose-producing tasks (working to secure the transportation cask on the trailer) would account for 12 to 19 percent of the total impact. The impacts are based on using crews of 13 workers [the number of workers

Table J-14. At-reactor reference loading operations—collective impacts to involved workers.[a]

	Rail		Truck	
Task description	CD per MTU[b,c] (PWR - BWR)[d]	Percent of total impact	CD per MTU (PWR - BWR)	Percent of total impact
Install cask lids; flush cask interior; drain, dry and seal cask	0.025 - 0.024	40 - 31	0.126 - 0.126	43 - 40
Install cask binders, impact limiters, personnel barriers	0.010 - 0.009	15 - 12	0.056 - 0.055	19 - 18
Load SNF into cask	0.011 - 0.027	17 - 35	0.011 - 0.027	4 - 9
On-vehicle cask radiological decontamination and survey	0.003 - 0.003	5 - 4	0.018 - 0.018	6 - 6
Final inspection and radiation surveys	0.002 - 0.002	4 - 3	0.016 - 0.015	5 - 5
All other (19) activities	0.011 - 0.012	19 - 16	0.066 - 0.073	23 - 23
Task totals	*0.062 - 0.077*	*100 - 100*	*0.29 - 0.31*	*100 - 100*

a. Source: DIRS 101747-Schneider et al. (1987, p. 2.9).
b. CD/MTU = Collective dose (person-rem effective dose equivalent) per metric ton uranium. One MTU is approximately equal to 1 MTHM.
c. The at-reactor loading crew size is assumed to be 13 involved workers.
d. PWR = pressurized-water reactor; BWR = boiling-water reactor.

assumed in the DIRS 101747-Schneider et al. (1987, Section 2) study] dedicated solely to performing cask-handling work. The involved worker collective dose was calculated using the following formula:

$$\text{Collective dose (person-rem)} = A \times B \times C \times D \times E$$

where: A = number of pressurized-water or boiling-water reactor spent nuclear fuel shipments being analyzed under each transportation scenario (from Tables J-4 and J-5)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of pressurized-water or boiling-water reactor spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation, expressed as metric tons uranium per assembly (from Table J-13)

E = involved worker-specific collective dose in person-rem/metric ton uranium for each fuel type (from Table J-13)

Because worker doses are linked directly to the number of loading operations performed, the highest average individual doses under each transportation scenario would occur at the reactor sites having the most number of shipments. Accordingly, the average individual dose impacts were calculated for the limiting site using the equation:

$$\text{Average individual dose (rem per involved worker)} = (A \times B \times C \times D \times E) \div F$$

where: A = largest value for the number of shipments from a site under each transportation scenario (from Tables J-4 and J-5)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation in metric tons uranium per assembly (from Table J-13)

E = involved worker-specific collective dose in person-rem per metric ton uranium for each fuel type (from Table J-13)

F = involved worker crew size (set at 13 persons for both transportation scenarios; from Table J-14)

J.1.3.1.2 *Radiological Impacts of DOE Spent Nuclear Fuel and High-Level Radioactive Waste Loading Operations*

The methodology used to estimate impacts to workers during loading operations for commercial spent nuclear fuel was also used to estimate impacts of loading operations for DOE spent nuclear fuel and high-level radioactive waste. The exposure factor (person-rem per MTU) for loading boiling-water reactor spent nuclear fuel in truck casks at commercial facilities was used (see Table J-14). The exposure factor for truck shipments of boiling-water reactor spent nuclear fuel was based on a cask capacity of five boiling-water reactor spent nuclear fuel assemblies (about 0.9 MTU or 0.9 MTHM). The analysis used this factor because it would result in the largest estimates for dose per operation.

J.1.3.2 Methods and Approach for Analysis of Impacts from Incident-Free Transportation

The potential exists for human health impacts to workers and members of the public from incident-free transportation of spent nuclear fuel and high level radioactive waste. *Incident-free* transportation means normal accident-free shipment operations during which traffic accidents and accidents in which radioactive materials could be released do not occur (Section J.1.4. discusses accidents). Incident-free impacts could occur from exposure to (1) external radiation in the vicinity of the transportation casks, or (2) transportation vehicle emissions, both during normal transportation.

J.1.3.2.1 *Incident-Free Radiation Dose to Populations*

The analysis used the RADTRAN 5 computer model and program (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) to evaluate incident-free impacts for populations. The RADTRAN 5 input parameters used to estimate incident-free impacts are listed in Table J-15. Through extensive review (DIRS 101845-Maheras and Pippen 1995, Section 3 and 4), DOE has determined that this program provides reasonable, but conservative, estimates of population doses for use in the evaluation of risks of transporting radioactive materials, including spent nuclear fuel and high-level radioactive waste. DOE used the previous version, RADTRAN 4, to analyze transportation impacts for other environmental impact statements (for example, DIRS 101802-DOE 1995, Volume 1, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G). RADTRAN 4 was subjected to extensive review (DIRS 101845-Maheras and Pippen 1995, Sections 3 and 4). RADTRAN 5 is an upgrade to RADTRAN 4, and has been validated by comparison with dose measurements (DIRS 153967-Steinman and Kearfott 2000, all). RADTRAN 5 consistently overestimates doses from transported radioactive materials when the results are compared to measured doses. The program and associated database, using population densities from 1990 Census data escalated to 2035, calculated the collective dose to populations that live along transportation routes [within 800 meters (0.5 mile) of either side of the route]. Table J-16 lists the estimated number of people who live within 800 meters of national routes.

Table J-15. Input parameters and parameter values used for the incident-free national truck and rail transportation analysis, except stops.

Parameter	Legal-weight truck transportation	Rail transportation	Legal-weight truck and rail
Package type			Type B shipping cask
Package dimension	5.2 meters[a] long 1.0 meters diameter	5.06 meters long 2.0 meters diameter	
Dose rate			10 millirem per hour, 2 meters from side of vehicle[f]
Number of crewmen	2	5	
Distance from source to crew	3.1 meters[a]	152 meters[b]	
Speed			
Rural	88 km[c,d] per hour	64 km per hour	
Suburban	88 km/hr non-rush hour 44 km/hr rush hour	40 km per hour	
Urban	88 km/hr non-rush hour 44 km/hr rush hour	24 km per hour	
Input for stop doses: see Table J-17			
Number of people per vehicle sharing route	2	3	
Minimum and maximum distances to exposed population			30 meters to 800 meters
Population densities (persons per km²)[d]			
Rural			(e)
Suburban			(e)
Urban			(e)
One-way traffic count (vehicles per hour)			
Rural	470	1	
Suburban	780	5	
Urban	2,800	5	

a. To convert meters to feet, multiply by 3.2808.
b. Rail crew in transit would be too far and too well shielded from the external cask radiation to receive any dose. This number is not used in the calculation and is provided for information only.
c. To convert kilometers to miles, multiply by 0.62137.
d. Assumes general freight rather than dedicated service.
e. Population densities along transportation routes were estimated using the HIGHWAY and INTERLINE computer programs, then were extrapolated to 2035.
f. The actual (equivalent) input to RADTRAN 5 is 14 millirem per hour at 1 meter (3.3 feet) from the side of the vehicle.

Table J-16. Population within 800 meters (0.5 mile) of routes for incident-free transportation using 2035 population.

Transportation scenario	2035 population
Mostly legal-weight truck	10,400,000
Mostly rail	16,400,000

RADTRAN 5 uses the following information to estimate collective incident-free doses to the public:

- The external radiation dose rate around shipping casks
- The resident population density (number of people per square kilometer) in the census block groups that contain the route (from HIGHWAY or INTERLINE)
- In urban areas, a factor for nonresident population density
- The speed of the vehicle (truck or train)
- The number of shipments that would be transported over each route
- The density of vehicles (number of vehicles per kilometer) sharing the route with the shipment and the average number of people in each vehicle
- Conditions at vehicle stops, which are described in greater detail below.

Most of these parameters were developed using the data listed in Tables J-15 and J-17. The number of shipments that would use a transportation route was developed with the use of the CALVIN computer program discussed in Section J.1.1.1, the DOE Throughput Study (DIRS 100265-CRWMS M&O 1997, Section 6.1.1), data on DOE spent nuclear fuel and high-level radioactive waste inventories in Appendix A, and data from DOE sites (DIRS 104778-Jensen 1998, all). The analysis used CALVIN to estimate the number of shipments from each commercial site. The Throughput Study provided the estimated number of shipments of high-level radioactive waste from the four DOE sites. Information provided by the DOE National Spent Nuclear Fuel Program (DIRS 104778-Jensen 1998, all) and in Appendix A was used to estimate shipments of DOE spent nuclear fuel.

The analysis used a value of 10 millirem per hour at a distance of 2 meters (6.6 feet) from the side of a transport vehicle for the external dose rate around shipping casks. This value is the maximum allowed by regulations of the U.S. Department of Transportation for shipments of radioactive materials [49 CFR 173.441(b)]. Dose rates at distances greater than 2 meters from the side of a vehicle would be less. The dose rate at 30 meters (98 feet) from the vehicle would be less than 0.2 millirem per hour; at a distance of 800 meters (2,600 feet) the dose rate would be less than 0.0002 millirem per hour.

In addition, the analysis used RADTRAN 5 to estimate doses to people closer to the cask than the resident population along the route, and to people who would be exposed for longer periods of time. These populations would include the truck or rail crew, others working near the cask, people in vehicles that share the route with the shipment, members of the public at truck stops, and residents of the area near the truck and rail stops.

The analysis also uses the potential number of people close enough to shipments to be exposed to radiation from the casks. The analysis determined the estimated offlink number of people [those within the 1.6-kilometer (1-mile) region of influence] by multiplying the population densities (persons per square kilometer) in population zones through which a route would pass by the 1.6-kilometer width of the region of influence and by the length of the route through the population zones. Onlink populations (those sharing the route and people at stops along the route) were estimated using assumptions from other EISs that have evaluated transportation impacts (DIRS 101802-DOE 1995, Volume 1, Appendix I; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G). The travel distance in each population zone was determined for legal-weight truck shipments by using the HIGHWAY computer program (DIRS 104780-Johnson et al. 1993, all) and for rail shipments by using the INTERLINE

Table J-17. Input parameter values for stop doses for routine incident-free transportation.

Stop type	Population exposed	Minimum distance (meters)[a]	Maximum distance (meters)[a]	Stop time	Other
Doses to the public					
People at truck stops	6.9[b]	1[b]	15.8[b]	20 min[b]	845 km[c] between stops
Residents near truck stops	Rural, suburban, or urban[d]	30	800	20 min[b]	845 km between stops
Residents near truck walkaround inspections[e]	Rural, suburban, or urban	30	800	10 min	161 km between stops
Residents near rail classification stops	Rural, suburban, or urban	30	800	30 hr[a]	One stop at each end of trip
Residents near rail crew change stops	Rural, suburban, or urban	30	800	0.033 hr/km[b]	
Occupational stop doses					
Truck crew dose at rest/refuel stops	2	1	15.8	20 min	845 km between stops
Truck crew dose at walkaround inspectons	1	1	1	10 min	161 km between stops
	1	Dose rate = 2 mrem/hr by regulation			
Rail crew dose at classification stops	5	(e)		30 hr	One stop at each end of trip
Rail crew dose at crew change stops	5	Calculated by multiplying the classification stop dose by 0.0018/km: a distance-dependent worker exposure factor[f]			

a. To convert meters to feet, multiply by 3.2808.
b. Derived from DIRS 152084-Griego, Smith, and Neuhauser (1996, all).
c. km = kilometer; to convert kilometers to miles, multiply by 0.62137.
d. Values used in DIRS 152476-Sprung et al. (2000, pp. 3-5 to 3-9, Table 3.3).
e. DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, Appendix B) explains this calculation, which has been incorporated into RADTRAN 5.
f. DIRS 150898-Neuhauser and Kanipe (2000, pp. 51 to 52).

program (DIRS 104781-Johnson et al. 1993, all). These programs used 1990 census block group data to identify where highways and railroads enter and exit each type of population zone, which the analysis used to determine the total lengths of the highways and railroads in each population zone.

The third kind of information—the distances individuals live from the route used in the analysis—is the estimated the number of people who live within 800 meters (about 2,600 feet) of the route. The analysis assumed that population density is uniform in population zones.

The analysis used RADTRAN 5 to calculate exposures for the following groups:

- *Public along the route (Offlink Exposure):* Collective doses for persons living or working within 0.8 kilometer (0.5 mile) on each side of the transportation route.

- *Public sharing the route (Onlink Exposure):* Collective doses for persons in vehicles sharing the transportation route; this includes persons traveling in the same or opposite direction and those in vehicles passing the shipment.

- *Public during stops (Stops):* Collective doses for people who could be exposed while a shipment was stopped en route. For truck transportation, these would include stops for refueling, food, and rest and for brief inspections at regular intervals. For rail transportation, stops would occur in railyards at the beginning and end of each trip, and along the route to switch railcars from inbound trains to outbound trains traveling toward the Yucca Mountain site, and to change train crews and equipment (locomotives).

- *Worker exposure (Occupational Exposure):* Collective doses for truck and rail transportation crew members.

- *Security escort exposure (Occupational Exposure):* Collective doses for security escorts. In calculating doses to workers the analysis conservatively assumed that the maximum number of escorts required by regulations (10 CFR 73.37) would be present for urban, suburban, and rural population zones.

The sum of the doses for the first three categories is the total nonoccupational (public) dose.

The sensitivity analysis in Section J.1.3.2.2.3 evaluates impacts of requiring additional escorts such as escorts in separate vehicles for all parts of every shipment of loaded legal-weight truck casks and two escorts in all areas for rail shipments.

Table J-17 lists input parameter values for doses to public and workers at stops. RADTRAN 5 models stops separately, and does not use the "hours per kilometer of travel" of the RADTRAN 4 model. Documentation for a stop model for dose to the public at truck rest and refueling stops is in DIRS 152084-Griego, Smith, and Neuhauser (1996, all). Models for calculating doses to members of the public who reside near stops, as well as occupational doses, for truck and rail, are in DIRS 152476-Sprung et al. (2000, pp. 8-14 to 8-18). For each model, the analysis includes a population or population density component, a total stop-time component, and the calculation, using RADTRAN 5, of an "hour per kilometer" equivalent for consistency with the unit risk factors listed in Table J-18. The external dose rate from the cask for all stops is 10 millirem per hour at 2 meters (6.6 feet) from the cask.

Unit dose factors were used to calculate incident-free collective doses. The offlink unit risk factors listed in Table J-18 represent the dose that would be received by a population density of one person per square kilometer for one shipment of radioactive material moving a distance of 1 kilometer (0.62 mile) in the indicated population density zone, and reflect the assumption that the dose rate external to shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by U.S. Department of Transportation regulations—10 millirem per hour at 2 meters (6.6 feet) from the side of the transport vehicle (49 CFR 173.441). The onlink unit risk factors represent the doses that would be received by occupants of vehicles sharing the transportation route with the cargo. There are two kinds of stop dose unit risk factors: one for the resident population near stops, based on a population density of one person per square kilometer, and another for the public at rest and refueling stops, which is independent of population density. The incident-free dose from transporting a single shipment was determined by multiplying the appropriate unit dose factors by corresponding distances in each of the population zones through which the shipment route would pass and by the population density of the zone. The collective dose from all shipments from a site was determined by multiplying the dose from a single shipment by the number of shipments that would be required to transport the site's spent nuclear fuel or high-level radioactive waste to the repository. Collective dose was converted to the estimated number of latent cancer fatalities using conversion factors recommended by the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 22). These values are 0.0004 latent cancer fatality per person-rem for radiation workers and 0.0005 latent cancer fatality per person-rem for the general population.

J.1.3.2.2 *Methods Used To Evaluate Incident-Free Impacts to Maximally Exposed Individuals*

To estimate impacts to maximally exposed individuals, the same kinds of information as those used for population doses (except for population size) were needed. The analysis of doses to maximally exposed individuals used projected exposure times, the distance a hypothetical individual would be from a shipment, the number of times an exposure event could occur, and the assumed external radiation dose

Table J-18. Incident-free dose factors.

Factor		Barge	Heavy-haul truck	Rail	Legal-weight truck
Public					
Off-link[a] [rem per (persons per square kilometer) per kilometer]	Rural	1.72×10^{-7}	6.24×10^{-8}	3.90×10^{-8}	2.98×10^{-8}
	Suburban	1.72×10^{-7}	6.24×10^{-8}	6.24×10^{-8}	3.18×10^{-8}
	Urban	1.72×10^{-7}	6.24×10^{-8}	1.04×10^{-7}	3.18×10^{-8}
On-link[b] (person-rem per kilometer)	Rural		1.01×10^{-4}	1.21×10^{-7}	9.53×10^{-6}[c]
	Suburban		7.94×10^{-5}	1.55×10^{-6}	2.75×10^{-5}
	Urban		2.85×10^{-4}	4.29×10^{-6}	9.88×10^{-5}
Residents near rest/refueling stops (rem per person per kilometer)[d]	Rural		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
	Suburban		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
	Urban		3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Residents near classification stops (rem per person per square kilometer)	Suburban			1.59×10^{-5}	
Public including workers at rest/refueling stops (person-rem per kilometer)					7.86×10^{-6}
Workers					
Classification stops (person-rem)				8.07×10^{-3}	
In-transit rail stops (person-rem per kilometer)				1.45×10^{-5}	
In moving vehicle (person-rem per kilometer)	Rural	2.11×10^{-6}	5.54×10^{-6}		4.52×10^{-5}
	Suburban	2.11×10^{-6}	5.54×10^{-6}		4.76×10^{-5}
	Urban	2.11×10^{-6}	5.54×10^{-6}		4.76×10^{-5}
Walkaround inspection (person-rem per kilometer)			6.27×10^{-7}		1.93×10^{-5}

a. Offlink general population includes persons in the census block groups on the route; the population density in each census block group is assumed to be the population density in the half-mile on either side of the route.

b. Onlink general population included persons sharing the road or railway.

c. Onlink dose factors are larger than offlink because the onlink population (vehicles and persons per vehicle) is included in the dose factor, and because the vehicles are much closer to the radioactive cargo.

d. The methodology, equations, and data used to develop the unit dose factors are discussed in DIRS 152084-Griego, Smith, and Neuhauser (1996, all); DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, Chapter 3); and DIRS 152476-Sprung et al. (2000, Chapter 3).

rate 2 meters (6.6 feet) from a shipment (10 millirem per hour). These analyses used the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all). DOE has used RISKIND for analyses of transportation impacts in other environmental impact statements (DIRS 104382-DOE 1995, Appendix J; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendix E). RISKIND provides appropriate results for analyses of incident-free transportation and transportation accidents involving radioactive materials (DIRS 101845-Maheras and Pippen 1995, Sections 5.2 and 6.2; DIRS 102060-Biwer et al. 1997, all).

The maximally exposed individual is a hypothetical person who would receive the highest dose. Because different maximally exposed individuals can be postulated for different exposure scenarios, the analysis evaluated the following exposure scenarios.

- *Crew Members.* In general, truck crew members, would receive the highest doses during incident-free transportation (see discussions below). The analysis assumed that the crews would be limited to a total job-related exposure of 2 rem per year (DIRS 156764-DOE 1999, Article 211).

- *Inspectors (Truck and Rail).* Inspectors would be Federal or state vehicle inspectors. On the basis of information provided by the Commercial Vehicle Safety Alliance (DIRS 104597-Battelle 1998, all;

DIRS 156422-CVSA 2001, all), the analysis assumed an average exposure distance of 1 meter (3 feet) and an exposure duration of 1 hour (see discussion in J.1.3.2.2.2).

- *Railyard Crew Member.* For a railyard crew member working in a rail classification yard assembling trains, the analysis assumed an average exposure distance of 10 meters (33 feet) and an exposure duration of 2 hours (DIRS 101816-DOE 1997, p. E-50).

- *Resident.* The analysis assumed this maximally exposed individual is a resident who lives 30 meters (100 feet) from a point where shipments would pass. The resident would be exposed to all shipments along a particular route (DIRS 101802-DOE 1995, Volume 1, Appendix I, p. I-52).

- *Individual Stuck in Traffic (Truck or Rail).* The analysis assumed that a member of the public could be 1.2 meter (4 feet) from the transport vehicle carrying a shipping cask for 1 hour. Because these circumstances would be random and unlikely to occur more than once for the same individual, the analysis assumed the individual to be exposed only once.

- *Resident Near a Rail Stop.* The analysis assumed a resident who lives within 200 meters (660 feet) of a switchyard and an exposure time of 20 hours for each occurrence. The analysis of exposure for this maximally exposed individual assumes that the same resident would be exposed to all rail shipments to the repository (DIRS 101802-DOE 1995, Volume 1, Appendix I, p. I-52).

- *Person at a Truck Service Station.* The analysis assumed that a member of the public (a service station attendant) would be exposed to shipments for 49 minutes for each occurrence at a distance of 16 meters (52 feet) (DIRS 152084-Griego, Smith, and Neuhauser 1996, all). The analysis also assumed this individual would work at a location where all truck shipments would stop.

As discussed above for exposed populations, the analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.3.2.2.1 Estimation of Incident-Free Maximally Exposed Individuals in Nevada. This section presents the assumptions used to estimate incident-free exposures to maximally exposed individuals in Nevada.

Transporting spent nuclear fuel to the Yucca Mountain site by legal-weight or heavy-haul trucks would require transport through Nevada on existing roads and highways. The proximity of existing structures that could house a maximally exposed individual have been determined and the maximally exposed individual identified and potential dose calculated as discussed in Section J.1.3.2.2. DOE considered a number of different sources of information concerning the proximity of the maximally exposed individual to a passing truck carrying spent nuclear fuel or high-level radioactive waste.

- An analysis prepared for the City of North Las Vegas (DIRS 155112-Berger 2000, p. 104) locates the maximally exposed individual 15 meters (50 feet) from an intersection. This individual would be exposed for 1 minute per shipment and an additional 30 minutes per year due to traffic delays. DOE believes the conditions listed greatly exceed actual conditions that would be encountered. Nevertheless, the estimated dose to this maximally exposed individual would be 530 millirem over 24 years.

- DOE performed a survey to determine the location of and proximity to the proposed routes that identified potential maximally exposed individual locations as follows:

  – Residences approximately 5 meters (15 feet) from Highway 93 in Alamo, Nevada (DIRS 155825-Poston 2001, p. 10). The analysis estimated the dose to a maximally exposed individual at this location based on 10,000 heavy-haul truck shipments over 24 years. This estimated dose would be 25 millirem.

- The courthouse and fire station in Goldfield, Nevada, are 5.5 and 4.9 meters (18 and 15 feet), respectively (DIRS 155825-Poston 2001, p. 12) from the road. The analysis estimated the dose to maximally exposed individuals at this location assuming potential exposure to 10,000 heavy-haul truck shipments over 24 years. The estimated dose would be 56 millirem.

- The width of the cleared area for a branch rail line would be 60 meters (200 feet); therefore, the closest resident would be at least 30 meters (98 feet) from a branch rail line. A maximally exposed individual who would be a minimum distance of 30 meters from a branch rail line, assuming 10,000 shipments over 24 years, would receive an estimated dose of 2 millirem.

- The *Intermodal and Highway Transportation of Low-Level Radioactive Waste to the Nevada Test Site* (DIRS 155779-DOE 1999, VI pc-23, Table C-11) identifies the maximally exposed individual as residing between Barstow, California, and the Nevada Test Site approximately 10.7 meters (35 feet) from a highway over 24 years of shipments; this individual would receive an estimated 20 millirem.

As identified above, the maximally exposed individual dose over 24 years for transportation in Nevada would range from 2 to 530 millirem.

J.1.3.2.2.2 Incident-Free Radiation Doses to Inspectors. DOE estimated radiation doses to the state inspectors who would inspect shipments of spent nuclear fuel and high-level radioactive waste originating in, passing through, or entering a state. For legal-weight truck and railcar shipments, the analysis assumed that:

- Each inspection would involve one individual working for 1 hour at a distance of 1 meter (3.3 feet) from a shipping cask.
- The radiation field surrounding the cask would be the maximum permitted by regulations of the U.S. Department of Transportation (49 CFR 173.441).
- There would be no shielding between an inspector and a cask.

For rail shipments, the analysis assumed that:

- There would be a minimum of two inspections per trip—one at origin and one at destination—with additional inspections en route occurring at intermediate stops.
- Rail crews would conduct the remaining along-the-route inspections.

For legal-weight truck shipments, the analysis assumed that:

- On average, state officials would conduct two inspections during each trip – one at the origin and one at the destination.
- The inspectors would use the Enhanced North American Uniform Inspection Procedures and Out-of-Service Criteria for Commercial Highway Vehicles Transporting Transuranics, Spent Nuclear Fuel, and High-Level Radioactive Waste (DIRS 156422-CVSA 2001, all).

- The shipments would receive a Commercial Vehicle Safety Alliance inspection sticker on passing inspection and before departing from the 77 sites.

- Display of such a sticker would provide sufficient evidence to state authorities along a route that a shipment complied with U.S. Department of Transportation regulations (unless there was contradictory evidence), and there would be no need for additional inspections.

The analysis used the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all) to determine doses to state inspectors. The data used by the program to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For rail shipments, using the assumptions outlined above, the estimated value for whole-body dose to an individual inspector for one inspection would be 17 millirem. Under the mostly rail scenario in which approximately 400 rail shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 82 shipments in a year. This inspector would receive a dose of 1.4 rem. If this same inspector inspected 82 shipments per year over the 24 years of the Proposed Action, he or she would be exposed to 34 rem.

The use of the dose-to-risk conversion factors published by the International Commission on Radiation Protection projects this exposure to increase the likelihood of the inspector incurring a fatal cancer. The projection would add 2 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (DIRS 153066-Murphy 2000, p. 5) to 25 percent.

For shipments by legal-weight truck, the analysis used the RISKIND computer program to estimate doses to inspectors (DIRS 101483-Yuan et al. 1995, all). The data used by the program to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For this calculation, the analysis assumed that an inspector following Commercial Vehicle Safety Alliance procedures (DIRS 156422-CVSA 2001, all) would work for 1 hour at an average distance of 1 meter (3.3 feet) from the cask. The analysis assumed that a typical legal-weight truck cask would be about 1 meter in diameter and about 5 meters (16 feet) long and that the dose rate 1 meter from the cask surface would be 14 millirem per hour. A dose rate of 14 millirem per hour 1 meter from the surface of a truck cask is approximately equivalent to the maximum dose rate allowed by U.S. Department of Transportation regulations for exclusive-use shipments of radioactive materials (49 CFR 173.441).

Using these data, the RISKIND computer program calculated an expected dose of 18 millirem for an individual inspector. Under the mostly legal-weight truck scenario in which approximately 2,200 legal-weight truck shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 450 shipments in a year. This inspector would receive a dose of 8.1 rem. If this same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to approximately 200 rem. However, DOE would control worker exposure through administrative procedures (see DIRS 156764-DOE 1999, Article 211). Actual worker exposure would likely be 2 rem per year, or a maximum of 48 rem over 24 years. The use of the dose-to-risk conversion factors published by the International Commission on Radiation Protection projects this exposure to increase the likelihood of this individual contracting a fatal cancer. The projection would add about 2 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (DIRS 153066-Murphy 2000, p. 5) to 25 percent. As discussed below, however, doses to inspectors likely would be much smaller.

DOE implements radiation protection programs at its facilities where there is the potential for worker exposure to cumulative doses from ionizing radiation. The Department anticipates that the potential for individual whole-body doses such as those reported above would lead an involved state to implement such a radiation protection program. If similar to those for DOE facilities, the administrative control limit on individual dose would not exceed 2 rem per year (DIRS 156764-DOE 1999, Article 211), and the expected maximum exposure for inspectors would be less than 500 millirem per year.

Under the mostly legal-weight truck scenario, the annual dose to inspectors in a state that inspected all incoming legal-weight truck shipments containing spent nuclear fuel or high-level radioactive waste would be as much as 40 person-rem. Over 24 years, the population dose for these inspectors would be about 950 person-rem. This would result in about 0.38 latent cancer fatality (this is equivalent to a 47-percent likelihood that there would be 1 additional latent cancer fatality among the exposed group).

The EIS analysis assumed that shipments would be inspected in the state of origin and in the destination state. If each state required an inspection on entry, the total occupational dose over 24 years of operation for the mostly legal-weight truck scenario would increase from approximately 14,000 person-rem to approximately 21,000 person-rem, resulting in an additional 3 latent cancer fatalities to the occupationally exposed population.

J.1.3.2.2.3 Incident-Free Radiation Doses to Escorts. This section has been moved to Volume IV of this EIS.

J.1.3.2.3 *Vehicle Emission Impacts*

Human health impacts from exposures to vehicle exhaust depend principally on the distance traveled and on the impact factors for fugitive dust and exhaust particulates from truck (including escort vehicles) or rail emissions (DIRS 151198-Biwer and Butler 1999, all; DIRS 155786-EPA 1997, all; DIRS 155780-EPA 1993, all).

The analysis estimated incident-free impacts using unit risk factors that account for fatalities associated with emissions of pollution in urban, suburban, and rural areas by transportation vehicles, including escort vehicles. Because the impacts would occur equally for trucks and railcars transporting loaded or unloaded shipping casks, the analysis used round-trip distances. Escort vehicle impacts were included only for loaded truck shipment miles, but were included for round trips for rail escort cars.

The analysis used risk factors to estimate impacts. The factors considered the effects of population density near highways and railroads. For urban areas, the value used for truck transportation was about 5 latent fatalities per 100 million kilometers traveled (8 latent fatalities per 100 million miles) by trucks and 2 latent fatalities per 10 million kilometers traveled by railcars (3 latent fatalities per 10 million miles). For trucks traveling in suburban and rural areas, the respective risk factors used are about 3 latent fatalities in 100 million kilometers (5 in 100 million miles) and 3 in 10 billion kilometers (5 in 10 billion miles). For railcars traveling in suburban and rural areas, the respective risk factors used are about 9 latent fatalities in 100 million kilometers (1.5 in 10 million miles) and about 8 in 10 billion kilometers (1.5 in 1 billion miles).

Although the analysis estimated human health and safety impacts of transporting spent nuclear fuel and high-level radioactive waste, exhaust and other pollutants emitted by transport vehicles into the air would not measurably affect national air quality. National transportation of spent nuclear fuel and high-level radioactive waste, which would use existing highways and railroads, would average 14.2 million truck kilometers per year for the mostly truck case and 3.5 million railcar kilometers per year from the mostly rail case. The national yearly average for total highway and railroad traffic is 186 billion truck kilometers and 49 billion railcar kilometers (DIRS 148081-BTS 1999, Table 3-22). Spent nuclear fuel and high-level radioactive waste transportation would represent a very small fraction of the total national highway and railroad traffic (0.008 percent of truck kilometers and 0.007 percent of rail car kilometers). In addition, the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (DIRS 103405-NDOT 1997, p. 7), about 20 percent of which are trucks (DIRS 104727-Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation's highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask's design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (DIRS 101831-General Atomics 1993, pp. 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by U.S. Department of Transportation regulations (49 CFR 173.441). Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (DIRS 104794-CRWMS M&O 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition, DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, all; DIRS 101816-DOE 1997, all) provided information on radiological impacts from loading accidents.

DIRS 104794-CRWMS M&O (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (DIRS 103405-NDOT 1997, p. 7), about 20 percent of which are trucks (DIRS 104727-Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation's highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask's design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (DIRS 101831-General Atomics 1993, pp. 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by U.S. Department of Transportation regulations (49 CFR 173.441). Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (DIRS 104794-CRWMS M&O 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition, DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, all; DIRS 101816-DOE 1997, all) provided information on radiological impacts from loading accidents.

DIRS 104794-CRWMS M&O (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent

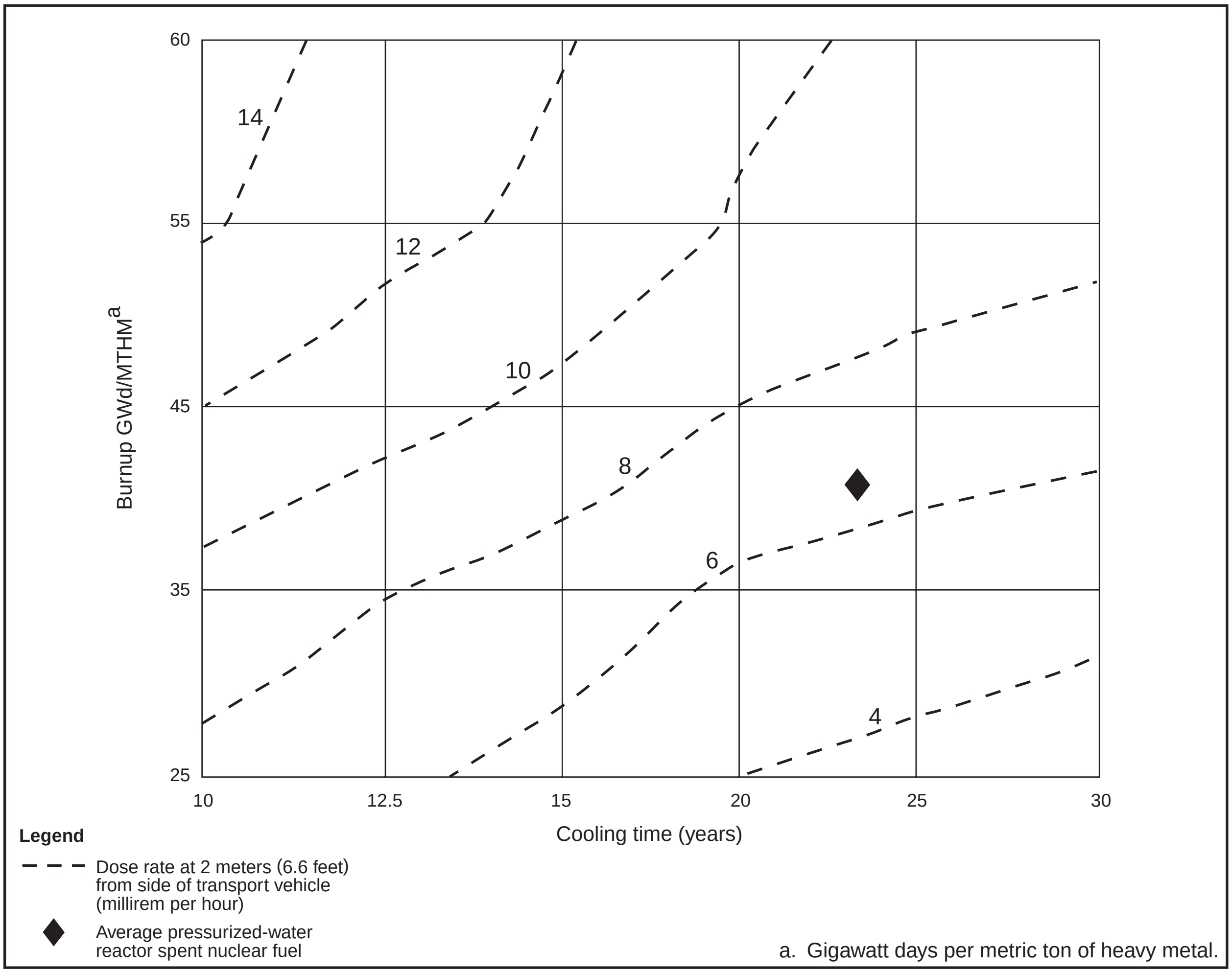

Figure J-7. Comparison of GA-4 cask dose rate and spent nuclear fuel burnup and cooling time.

nuclear fuel (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all) evaluated a comprehensive spectrum of accident-initiating events. These events included fires, chemical explosions, seismic events, nuclear criticality, tornado strikes and tornado-generated missile impacts, lightning strikes, volcanism, canister and basket drop, loaded shipping cask drop, and interference (bumping, binding) between the transfer cask and storage module. The DOE environmental impact statements for the interim management of spent nuclear fuel and high-level radioactive waste (DIRS 101802-DOE 1995, Volume 1, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) included radiological impacts from potential accident scenarios associated with preparing, storing, and shipping these materials. These EISs do not discuss quantitative radiological impacts for accident scenarios associated with material loading, but do contain estimates of radiological impacts from accident scenarios for the spent nuclear fuel and high-level radioactive waste management activities considered. As discussed for routine loading operations, this analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

The DIRS 104794-CRWMS M&O (1994, all) study concluded that radiological impacts from handling incidents would be small. The population dose (person-rem) for accidents in handling the four cask systems considered in the study would vary from 0.1 rem to 0.04 rem. This dose would be the total for all persons who would be exposed, onsite workers as well as the public. The highest estimated dose (0.1 person-rem) could result in 0.00005 latent cancer fatality in the exposed population.

J.1.4.1.2 *Industrial Safety Impacts of Loading Operations at Commercial Facilities*

The principal industrial safety impact parameters of importance to commercial industry and the Federal Government are (1) total recordable (injury and illness) cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The frequency of these impacts under the Proposed Action and the inventory modules (Modules 1 and 2) was projected using the involved worker level of effort, expressed as the number of full-time equivalent worker multiples, that would be needed to conduct shipment tasks. The workplace loss incidence rate for each impact parameter [as shown in a Bureau of Labor Statistics summary (DIRS 148091-BLS 1998, all)] was used as a multiplier to convert the level of effort to expected industrial safety losses.

DOE did not explicitly analyze impacts to noninvolved workers in its earlier reports (DIRS 101747-Schneider et al. 1987, all; DIRS 104791-DOE 1992, all). However, for purposes of analysis in this EIS, DOE estimated that impacts to noninvolved workers would be 25 percent of the impacts to the involved workforce. This assumption is based on (1) the DOE estimate that about one of five workers assigned to a specific task would perform administrative or managerial duties, and (2) the fact that noninvolved worker loss incidence rates are generally less than those for involved workers (see Appendix F, Section F.2.2.2).

The estimated involved worker full-time equivalent multiples for each shipment scenario were estimated using the following formula:

$$\text{Involved worker full-time equivalent multiples} = (A \times B \times C \times D) \div E$$

where: A = number of shipments (from Tables J-5 and J-6)

B = average loading duration for each shipment by fuel type and conveyance mode (workdays; from Table J-13)

C = workday conversion factor = 8 hours per workday

D = involved worker crew size (13 workers; from Table J-14)

E = full-time equivalent conversion factor = 2,000 worker hours per full-time equivalent

The representative Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday case, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was then multiplied by the involved worker full-time equivalent multiples to project the associated incidence. The involved worker total recordable case incidence rate used was that reported for the Trucking and Warehousing sector for 1998 because neither the Nuclear Regulatory Commission nor the Bureau of Labor Statistics maintains data on commercial power reactor industrial safety losses. The total recordable case incidence rate, 145,700 cases in a workforce of 1.74 million workers (8.4 total recordable cases per 100 full-time equivalents), is the averaged loss experience for 1998. The Trucking and Warehousing sector was chosen because DOE assumed the industrial operations and hazards associated with activities in this sector would be representative of those encountered in handling spent nuclear fuel casks at commercial power reactor sites and DOE facilities. Because lost workday cases are linked to the total recordable case experience (that is, each lost workday case would have to be included in the total recordable case category), the same period of record and facilities was used in the selection of the involved worker lost workday case incidence rate [80,800 lost workday cases in a workforce of 1.74 million workers (4.6 lost workday cases per 100 full-time equivalents)].

The involved worker fatality incidence rate reported by the Bureau of Labor Statistics (1.8 fatalities among 100,000 workers) for the Trucking and Warehousing sector during the DIRS 148091-BLS (1998, all) period of record was used.

DOE used the same Bureau of Labor Statistics data sources to estimate total recordable case, lost workday case, and fatality incidence rates for noninvolved workers.

J.1.4.1.3 *Industrial Safety Impacts of DOE Loading Operations*

The technical approach and loss multipliers discussed in Section J.1.4.1.2 for commercial power reactor sites analysis were used for the analysis of spent nuclear fuel and high-level radioactive waste loading impacts at DOE sites. Because no information existed on the high-level radioactive waste loading duration for the truck and rail transportation modes, DOE assumed that the number of full-time equivalent involved workers for the two transportation modes would be the same as that for the DOE sites shipping spent nuclear fuel. For those sites, the average number of full-time equivalent workers would be about 0.07 and 0.12 per shipment for the truck and rail transportation modes, respectively.

J.1.4.2 Transportation Accident Scenarios

J.1.4.2.1 *Radiological Impacts of Transportation Accidents*

Potential consequences and risks of transportation would result from three possible types of accidents: (1) accidents in which there is no effect on the cargo and the safe containment by transportation packages is maintained, (2) accidents in which there is no breach of containment, but there is loss of shielding because of lead shield displacement, and (3) accidents that release and disperse radioactive material from safe containment in transportation packages. Such accidents, if they occurred, would lead to impacts to human health and the environment. The following sections describe the methods for analyzing the risks and consequences of accidents that could occur in the course of transporting spent nuclear fuel and high-level radioactive waste to a nuclear waste repository at the Yucca Mountain site. They discuss the bases for, and methods for, determining rates at which accidents are assumed to occur, the severity of these accidents, and the amounts of materials that could be released. Accident rates, severities, and the corresponding quantities of radioactive materials that could be released are essential data used in the analyses. Appendix A presents the quantities of radioactive materials in a typical pressurized-water reactor spent nuclear fuel assembly used in the analysis of accident consequences and risks. Legal-weight truck casks would usually contain four pressurized-water reactor spent nuclear fuel assemblies, and rail casks would usually contain 24 (see Table J-3).

In addition to accident rates and severities, an important variable in assessing impacts from transportation accident scenarios is the type of material that would be shipped. Accordingly, this appendix presents information used in the analyses of impacts of accidents that could occur in the course of transporting commercial pressurized- and boiling-water reactor fuels, DOE spent nuclear fuels, and DOE high-level radioactive waste.

For exposures to ionizing radiation and radioactive materials following accidents, risks were analyzed in terms of dose and latent cancer fatalities to the public and workers. The analyses of risk also addressed the potential for fatalities that would be the direct result of mechanical forces and other nonradiological effects that occur in everyday vehicle and industrial accidents.

The transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site would be conducted in a manner that complied fully with regulations of the U.S. Department of Transportation and Nuclear Regulatory Commission. These regulations specify requirements that promote safety and security in transportation. The requirements apply to carrier

POTENTIAL EFFECTS OF HUMAN ERROR ON ACCIDENT IMPACTS

The accident scenarios described in this chapter would be mostly a direct consequence of error on the part of transport vehicle operators, operators of other vehicles, or persons who maintain vehicles and rights-of-way. The number and severity of the accidents would be minimized through the use of trained and qualified personnel.

Others have argued that other kinds of human error could also contribute to accident consequences: (1) undetected error in the design and certification of transportation packaging (cask) used to ship radioactive material, (2) hidden or undetected defects in the manufacture of these packages, and (3) error in preparing the packages for shipment. DOE has concluded that regulations and regulatory practices of the Nuclear Regulatory Commission and the Department of Transportation address the design, manufacture, and use of transportation packaging and are effective in preventing these kinds of human error by requiring:

- Independent Nuclear Regulatory Commission review of designs to ensure compliance with requirements (10 CFR Part 71)
- Nuclear Regulatory Commission-approved and audited quality assurance programs for design, manufacturing, and use of transportation packages

In addition, Federal provisions (10 CFR Part 21) provide additional assurance of timely and effective actions to identify and initiate corrective actions for undetected design or manufacturing defects. Furthermore, conservatism in the approach to safety incorporated in the regulatory requirements and practices provides confidence that design or manufacturing defects that might remain undetected or operational deficiencies would not lead to a meaningful reduction in the performance of a package under normal or accident conditions of transportation.

operations; in-transit security; vehicles; shipment preparations; documentation; emergency response; quality assurance; and the design, certification, manufacture, inspection, use, and maintenance of packages (casks) that would contain the spent nuclear fuel and high-level radioactive waste.

Because of the high level of performance required by regulations for transportation casks (49 CFR Part 173 and 10 CFR Part 71), the Nuclear Regulatory Commission estimates that in more than 99.99 percent of rail and truck accidents no cask contents would be released (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76). The 0.007 percent of accidents, including those for which there is no release and those that could cause a release of radioactive materials, can be described by a spectrum of accident severity. In general, as the severity of an accident increases, the fraction of radioactive material contents that could be released from transportation casks also increases. However, as the severity of an accident increases it is generally less likely to occur. DIRS 152476-Sprung et al. (2000, all) developed an accident analysis methodology that uses this concept of a spectrum of severe accidents to calculate the probabilities and consequences of accidents that could occur in transporting highly radioactive materials.

The analysis in DIRS 152476-Sprung et al. (2000, pp. 7-74 and 7-76), which DOE adopted for the analysis in the EIS, estimates that 0.01 percent of accidents to steel-lead-steel casks could result in some lead displacement and consequent loss of shielding. The analysis evaluated the radiological impacts (population dose risk) of shielding loss and the impacts of potential releases of radioactive material. The loss-of-shielding analysis included estimates of radiological impacts for the percentage of accidents in which there would be neither loss of shielding nor release of radioactive material. In such accidents, the vehicle carrying the spent nuclear fuel would be stopped along the route for an extended period and nearby residents would not be evacuated.

Although the approach of DIRS 152476-Sprung et al. (2000, pp. 7-7 to 7-12), which is used in this EIS, provides a method for determining the frequency with which severe accidents can be expected to occur, their severity, and their consequences, a method does not exist for predicting where along routes accidents would occur. Therefore, the analyses of impacts presented here used the approach used in RADTRAN 5 (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all). This method assumes that accidents could occur at any location along routes, with their frequency of occurrence being determined by the accident rate characteristic of the states through which the route passes, the length of the route, and the number of shipments that travel the route.

The transportation accident scenario analysis evaluated radiological impacts to populations and to hypothetical maximally exposed individuals and estimated fatalities that could occur from traffic accidents. It included both rail and legal-weight truck transportation. The analysis used the RADTRAN 5 (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) and RISKIND (DIRS 101483-Yuan et al. 1995, all) models and computer programs to determine accident consequences and risks. DOE has used both codes in recent DOE environmental impact statements (DIRS 101802-DOE 1995, Volume 1, Appendix J; DIRS 101812-DOE 1996, Appendix E; DIRS 101816-DOE 1997, Appendixes F and G) that address impacts of transporting radioactive materials. The analyses used the following information to determine the consequences and risks of accidents for populations:

- Routes from the 77 sites to the repository and their lengths in each state and population zone
- The number of shipments that would be transported over each route
- State-specific accident rates
- The kind and amount of radioactive material that would be transported in shipments
- The type of cask used in spent nuclear fuel and high-level radioactive waste transportation
- Probabilities of amount of lead displacement that would result in loss of shielding
- Probabilities of release and fractions of cask contents that could be released in accidents
- The number of people who could be exposed to radiological material from accidents and how far they lived from the routes
- The length of time people could be exposed to external radiation in accidents that do not involve releases of radioactive material
- Exposure scenarios that include multiple exposure pathways, state-specific agricultural factors, and atmospheric dispersion factors for neutral and stable conditions applicable to the entire country for calculating radiological impacts

The analysis used the same routes and lengths of travel as the analysis of incident-free transportation impacts discussed above.

DOE used the CALVIN computer code discussed earlier, the DOE Throughput Study (DIRS 100265-CRWMS M&O 1997, all), and information provided by the DOE National Spent Nuclear Fuel Program (DIRS 104778-Jensen 1998, all) to calculate the number of shipments from each site and, thus, the number of shipments that would use a particular route.

TRANSPORTATION ACCIDENT RADIOLOGICAL DOSE RISK

The risk to the general public of radiological consequences from transportation accidents is called *dose risk* in this EIS. Dose risk is the sum of the products of the probabilities (dimensionless) and the consequences (in person-rem) of all potential transportation accidents.

The probability of a single accident is usually determined by historical information on accidents of a similar type and severity. The consequences are estimated by analysis of the quantity of radionuclides likely to be released, potential exposure pathways, potentially affected population, likely weather conditions, and other information.

As an example, the dose risk from a single accident that had a probability of 0.001 (1 chance in 1,000), and would cause a population dose of 22,000 person-rem in a population if it did occur, would be 22 person-rem. If that population was subject to 1,000 similar accident scenarios, the total dose risk would be 22,000 person-rem. Using the conversion factor of 0.0005 latent cancer fatality per person-rem, an analysis would estimate a health and safety risk of 11 latent cancer fatalities from this population dose risk.

The state-specific accident rates (accidents and fatalities per kilometer of vehicle travel) used in the analysis included accident statistics for commercial motor carrier operations for the Interstate Highway System, other U.S. highways, and state highways for each of the 48 contiguous states (DIRS 103455-Saricks and Tompkins 1999, all). The analysis also used average accident and fatality rates for railroads in each state. The data specifically reflect accident and fatality rates that apply to commercial motor carriers and railroads.

Appendix A contains information on the radioactive material contents of shipments. Appendix A, Section A.2.1.5 describes the characteristics of the spent nuclear fuel and high-level radioactive waste that would be shipped. The analysis assumed that the inventory of radioactive materials in shipments would be representative pressurized-water reactor spent nuclear fuel that had been removed from reactors for 15 years. Appendix A describes this inventory. The estimated impacts would be less if the analysis used the characteristics of a typical boiling-water reactor spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel, which the analysis assumed would be removed from reactors 5 years before its shipment to the repository), or high-level radioactive waste. Section J.1.2.1.1 describes the casks.

The analysis also used the number of people who potentially would be close enough to transportation routes at the time of an accident to be exposed to radiation or radioactive material released from casks, and the distances these people would be from the accidents. It used the HIGHWAY and INTERLINE computer programs to determine this estimated number of people and their distances from accidents. HIGHWAY and INTERLINE used 1990 Census data for this analysis. In addition, the analysis escalated impacts to account for changes in population from 1990 to 2035 using Bureau of the Census projections. The analysis assumed that the region of influence extended 80 kilometers (50 miles) from an accident involving a release of radioactive material, and 800 meters (0.5 mile) on either side of the route for accidents with no release.

Accident Severity Categories and Conditional Probabilities

For accidents involving release of radioactive material, DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) organizes truck and rail accident scenarios according to estimated severity, likelihood of that severity, and releases that might result. Nineteen scenarios for legal-weight truck and 21 scenarios for rail were postulated. Classification matrices were made for four generic casks and pressurized-water and boiling-water reactor commercial spent nuclear fuel types. Figures J-8a and J-8b show the classification matrices for the cask and fuel used in the analysis of impacts presented in this EIS: steel-depleted uranium-steel casks for truck shipments of pressurized-water reactor fuel and steel-lead-steel casks for rail shipments of pressurized-water reactor fuel. Use of data from DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for other cask types and for boiling-water reactor spent nuclear fuel would lead to smaller impacts.

Figures J-8a and J-8b have been moved to Volume IV of this EIS.

Accident severity is a function of two variables. The first variable is the mechanical force that occurs in impacts. In the figures, mechanical force is represented by the impact velocity along the vertical axis of the matrix. The second variable is thermal energy, or the heat input to a cask engulfed by fire, also along the horizontal axis. Thermal energy is represented by the midpoint temperature of a cask's lead shield wall following heating, as in a fire.

Because all accident scenarios that would involve casks can be described in these terms, the severity of accidents can be analyzed independently of specific accident sequences. In other words, any sequence of events that results in an accident in which a cask is subjected to mechanical forces, within a certain range of values, and possibly fire is assigned to the accident severity category associated with the applicable ranges for the two parameters. This accident severity scheme enables analysis of a manageable number of accident situations while accounting for all reasonably foreseeable transportation accidents, including accidents with low probabilities but high consequences and those with high probabilities but low consequences. The scheme also encompasses by inference all scenarios that result in a particular outcome.

For the analysis of impacts, a conditional probability was assigned to each accident severity category. Figures J-8a and J-8b show the conditional probabilities developed in DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) for the accident severity matrix. These conditional probabilities were used in the analysis of impacts presented in this appendix. The conditional probabilities are the chances that accidents will involve the mechanical forces and the heat energy in the ranges that apply to the categories. For example, accidents that would fall into Cell 19 in the lower left corner of Figure J-8a, which represents the least severe accident in the matrix, would be likely to make up 99.993 percent of all accidents that would involve truck shipments of casks carrying spent nuclear fuel. The mechanical forces and heat in accidents in this category would not exceed the regulatory design standards for casks. Using the information in the figure, in an accident in this category the safety function of the cask would not be lost and the temperature of the cask would not change. These conditions are within the range of damage that would occur to casks subjected to the hypothetical accident conditions tests that Nuclear Regulatory Commission regulations require a cask to survive (10 CFR Part 71). Accidents in Cell 7 or Cell 12, for example, which would cause considerable damage to a cask, are very severe but very infrequent. Cell 7 accidents would occur an estimated 3 times in each 1 trillion truck accidents, and Cell 12 accidents would occur an estimated 2 times in each 100 trillion truck accidents.

The probabilities shown in each cell of Figures J-8a and J-8b are the conditional probabilities derived from event trees (for example, DIRS 152476-Sprung et al. 2000, p. 7-10) that are assigned to each severity category. These conditional probabilities are the chances that, if an accident occurs, that accident will involve the impact speed and the heat energy in the ranges that apply to the categories. The analysis of accident risks presented in this appendix used the frequency that would be likely for accidents in each of the severity categories. This frequency was determined by multiplying the category's conditional probability by the accident rates for each state's urban, suburban, and rural population zones and by the shipment distances in each of these zones, and then adding the results. The accident rates in the population density zones in each state are distinct and correspond to traffic conditions, including average vehicle speed, traffic density, and other factors, including rural, suburban, or urban location.

Accident Releases

To assess radiological consequences, cask release fractions for each accident severity category for each chemically and physically distinct radioisotope were calculated (DIRS 152476-Sprung et al. 2000, Sections 7.3 and 7.4). The *release fraction* of each isotope is the fraction of that isotope in the cask that could be released from the cask in a given severity of accident. Release fractions vary according to spent nuclear fuel type and the physical/chemical properties of the radioisotopes. Almost all of the radionuclides in spent nuclear fuel are chemically stable and do not react chemically when released. All are physically stable and most are in solid form. Gaseous radionuclides, such as krypton-85, could be released if both the fuel cladding and cask containment boundary were compromised. Volatile radionuclides, like radiocesium iodide, could be released in part, and would also deposit on the inside of the cask, depending on the temperature of the cask.

DIRS 152476-Sprung et al. (2000, p. 7-71) developed release fractions for commercial spent nuclear fuel from both boiling-water and pressurized-water reactors. Figures J-8a and J-8b provide examples of these release fractions. The analysis estimated the amount of radioactive material released from a cask in an accident by multiplying the approximate release fraction by the number of fuel assemblies in a cask (see Table J-3) and the radionuclide activity of a spent nuclear fuel assembly (see Appendix A). To provide perspective, the release fraction for a category 6 accident involving a large rail cask carrying 60 assemblies of spent boiling-water reactor fuel could result in an estimated release of about 48 curies of cesium isotopes. For this analysis, the release fractions developed by DIRS 152476-Sprung et al. (2000, pp. 7-73 to 7-76) were used for commercial pressurized-water and boiling-water reactor fuel. In addition, the analysis used release fractions for spent nuclear fuel from training, research and isotope reactors built by General Atomics (commonly called *TRIGA* spent nuclear fuel), aluminum-based fuel, uranium-carbide fuel, and vitrified high-level radioactive waste.

Accidental Loss of Shielding

Under accident conditions, a reduction in the radiation shielding provided by the spent nuclear fuel cask could occur. An accident where shielding is lost or its effectiveness reduced is often referred to as a loss of shielding accident. Shielding could be lost in high-impact collisions, which could cause lead shielding in a cask to slump towards the point of impact, or in a long-duration, intense fire, which could cause lead shielding to melt and expand. As the lead shielding cooled and solidified, it could shrink and possibly leave voids. Puncture of the cask could result in loss of melted lead. Loss of shielding can occur only in casks that use lead as shielding; it cannot occur in casks that use steel or depleted uranium for shielding.

Using the data presented in Table 8.12 from DIRS 152476-Sprung et al. (2000, pp. 8-47 to 8-50), conditional probabilities, radiation dose rates, and an exposure factor for calculating collective dose were developed for 6 accident severity categories that represent a complete spectrum of loss of shielding accidents (see Table J-19) for 4 cask types. The exposure factors were calculated using RADTRAN 5 assuming that a population from 30 to 800 meters (98 to 2,600 feet) was exposed for 12 hours. Unit risk factors were calculated by multiplying the exposure factor by the accident conditional probability. Category 1 represents accidents where there was no loss of shielding and resulting radiation dose rate and exposure factor are for an undamaged cask. This is the only category applicable to steel or depleted uranium casks. Categories 2 through 6 represent accidents that involve various impact speeds and temperatures. Table J-20 shows the relationship of the 6 accident severity categories for loss of shielding presented here to the 21 rail accident cases and 19 truck accident cases discussed in DIRS 152476-Sprung et al. (2000, pp. 7-73 through 7-76).

Table J-19. Loss-of-shielding conditional probabilities, radiation dose rates, and exposure factors for four cask types and six accident severity categories.[a]

Cask type	Conditional probability	Radiation dose rate (rem per hour)[b]	Exposure factor (person-rem per person/km^2)[c]
Steel-lead-steel rail			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	6.4×10^{-6}	8.2	7.2×10^{-3}
Category 3	4.9×10^{-5}	2.4	2.0×10^{-3}
Category 4	4.5×10^{-7}	1.3×10^{1}	1.2×10^{-2}
Category 5	2.4×10^{-5}	2.9	2.4×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	3.0×10^{-2}
Steel-lead-steel truck			
Category 1	0.9999	1.4×10^{-2}	3.9×10^{-5}
Category 2	4.5×10^{-7}	1.3×10^{1}	7.1×10^{-3}
Category 3	4.9×10^{-5}	2.4	8.5×10^{-4}
Category 4	6.4×10^{-6}	8.2	3.5×10^{-3}
Category 5	2.4×10^{-5}	2.9	1.0×10^{-3}
Category 6	5.2×10^{-9}	2.4×10^{1}	2.2×10^{-2}
Monolithic rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}
Steel-depleted uranium-steel rail			
Category 1	1.0000	1.4×10^{-2}	3.9×10^{-5}
Category 2	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 3	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 4	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 5	0.0	1.4×10^{-2}	3.9×10^{-5}
Category 6	0.0	1.4×10^{-2}	3.9×10^{-5}

a. Source: Calculated by RADTRAN 5.
b. Radiation dose rate at 1 meter from the cask.
c. km^2 = square kilometer; 1 square kilometer = 0.39 square miles or 247.1 acres.

Table J-20. Grouping of accident cases into accident categories.[a]

Accident category	Rail accident cases	Truck accident cases
Category 1	21	19
Category 2	1, 7, 8, 9	2, 10, 11, 12
Category 3	20	18
Category 4	2, 10, 11, 12	1, 7, 8, 9
Category 5	4, 5, 6	4, 5, 6
Category 6	3, 13, 14, 15, 16, 17, 18, 19	3, 13, 14, 15, 16, 17

a. Source: Adapted from DIRS 152476-Sprung et al. (2000, Table 8.12).

The unit risk factor for a category was multiplied by the shipment distance, the number of shipments, the accident rate, and the population density to yield the radiation dose to the exposed population for the category. The radiation doses for all categories were summed to yield the overall radiation dose from all categories of loss of shielding accidents.

Atmospheric Conditions

For the analyses of accident risk and consequences, releases of radioactive materials from casks during and following severe accidents were assumed to be into the air where these materials would be carried by wind. Because it is not possible to predict specific locations where transportation accidents would occur, average U.S. atmospheric conditions were used.

RADTRAN 5, which DOE used in the analysis, contains embedded tables giving the "footprint" of the dispersed plume in curves of constant concentration, called isopleths, for each of the six Pasquill stability classes (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, Chapter 4). These tables incorporate wind speed, downwind distance, area of the footprint, and dilution of the plume. Dispersion of releases from an accident are then modeled by combining these tables to represent national average weather conditions. The RADTRAN 5/database combination was then used in the analysis to calculate an accident *dose risk* incorporating the risk from inhaled and ingested radioactive material, and external radiation from radioactive material deposited on the ground and suspended in the air.

Table J-21 lists the frequency at which atmospheric stability and wind speed conditions occur in the contiguous United States. The data, which are averages for 177 meteorological data collection locations, were used in conjunction with the RADTRAN 5/database to calculate the population (collective) dose risk from any accident, as well as with the RISKIND computer program (DIRS 101483-Yuan et al. 1995, all). RISKIND was used to estimate the consequences of maximum reasonably foreseeable accidents and acts of sabotage.

Table J-21. Frequency of atmospheric and wind speed conditions – U.S. averages.[a]

Atmospheric stability class	Wind speed condition						Total
	WS(1)	WS(2)	WS(3)	WS(4)	WS(5)	WS(6)	
A	0.00667	0.00444	0.00000	0.00000	0.00000	0.00000	0.01111
B	0.02655	0.02550	0.01559	0.00000	0.00000	0.00000	0.06764
C	0.01400	0.02931	0.05724	0.01146	0.00122	0.00028	0.11351
D	0.03329	0.07231	0.15108	0.16790	0.03686	0.01086	0.47230
E	0.00040	0.04989	0.06899	0.00146	0.00016	0.00003	0.12093
F	0.10771	0.08710	0.00110	0.00000	0.00000	0.00000	0.19591
G	0.01713	0.00146	0.00000	0.00000	0.00000	0.00000	0.01859
F+G	0.12485	0.08856	0.00110	0.00000	0.00000	0.00000	0.21451
Totals	*0.20576*	*0.27000*	*0.29401*	*0.18082*	*0.03825*	*0.01117*	*1.00000*
Wind speed (meters per second)[b]	0.89	2.46	4.47	6.93	9.61	12.52	

a. Source: DIRS 104800-CRWMS M&O (1999, p. 40).
b. To convert meters per second to miles per hour, multiply by 2.237.

In calculating estimated values for consequences, RISKIND used the atmospheric stability and wind speed data to analyze the dispersion of radioactive materials in the atmosphere that could follow releases in severe accidents. Using the results of the dispersion analysis, RISKIND calculated values for radiological consequences (population dose and dose to a maximally exposed individual). These results were placed in order from largest to smallest consequence. Following this order, the probabilities of the atmospheric conditions associated with each set of consequences were incorporated to provide a cumulative probability. This procedure was followed to identify the most severe accident consequences that would have a cumulative estimated annual frequency of occurrence of at least 1 in 10 million. The procedure was carried out separately for urban and rural accidents and for neutral and stable atmospheric conditions.

Exposure Pathways

Radiation doses from released radioactive material were calculated for an individual who is postulated to be near the scene of an accident and for populations within 80 kilometers (50 miles) of an accident location. Doses were determined for rural, suburban, and urban population groups. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine and immersion in a plume of radioactive material) from a passing cloud of contaminants; ingestion from contaminated crops; direct exposure from radioactivity deposited on the ground (groundshine); and inhalation of radioactive particles resuspended by wind from the ground.

Emergency Response, Interdiction, Dose Mitigation, and Evacuation

The RADTRAN 5 computer program that DOE used to estimate radiological risks allows the user to include assumptions about the postaccident remediation of radioactive material contamination of land where people live. The analysis using the program assumed that, after an accident, contaminants would continue to contribute to population dose through three pathways—groundshine, inhalation of resuspended particulates, and, for accidents in rural areas, ingestion of foods produced on the contaminated lands. It also assumed that medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of accidents.

For a discussion of emergency response to transportation accidents, see Appendix M, Section M.5.

Similarly, the RISKIND (DIRS 101483-Yuan et al. 1995, all) computer program includes assumptions about response, interdiction, dose mitigation, and evacuation for calculating radiological consequences (dose to populations and maximally exposed individuals). In estimating consequences of maximum reasonably foreseeable accidents during the transportation of spent nuclear fuel and high-level radioactive waste to the repository, the analysis assumed the following:

- Populations would continue to live on contaminated land for 1 year.

- There would be no radiological dose to populations from ingestion of contaminated food. Food produced on land contaminated by a maximum reasonably foreseeable accident would be embargoed from consumption.

- Medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of an accident.

The analysis of a maximum foreseeable loss-of-shielding accident assumed that the vehicle would be stopped at the site of the accident for 12 hours.

Emergency management personnel (first responders) would be between 2 and 10 meters (6.6 and 33 feet) from the vehicle for about an hour to secure the vehicle and keep people away. For about half of this time, the emergency personnel would be exposed to that section of the cask where shielding had been lost.

The analysis of radiological risks to populations and estimates of consequences of maximum reasonably foreseeable accidents did not explicitly address local, difficult-to-evacuate populations such as those in prisons, hospitals, nursing homes, or schools. However, the analysis addressed the potential for accidents to occur in urban areas with high population densities and used the assumptions regarding interdiction, evacuation, and other intervention actions discussed above. These assumptions encompass the consequences and risks that could arise as a result of time to implement measures to mitigate the consequences for some population groups.

Health Risk Conversion Factors

The health risk conversion factors used to estimate expected latent cancer fatalities from radiological exposures are presented in International Commission on Radiological Protection Publication 60 (DIRS 101836-ICRP 1991, p. 22). These factors are 0.0005 latent cancer fatality per person-rem for members of the public and 0.0004 latent cancer fatality per person-rem for workers. For accidents in which individuals would receive doses greater than 20 rem over a short period (high dose/high dose rate), the factors would be 0.0010 latent cancer fatality per rem for a member of the public and 0.0008 latent cancer fatality per rem for workers.

Assessment of Accident Risk

The RADTRAN 5 database (DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) was used in calculating risks from transportation of spent nuclear fuel and high-level radioactive waste. The code calculated unit-risk factors (person-rem per person per square kilometer per curie) for the radionuclides of concern in the inventory being shipped (see Appendix A). The unit-risk factors from RADTRAN 5 were combined with conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity categories, for each mode of transportation, cask, and spent nuclear fuel or high-level radioactive waste form. For each site traversed, results of this analysis were combined with urban, suburban, and rural distances and population densities, and with the number of shipments. Ingestion dose risks were calculated separately by combining conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity collective categories, and rural distances and numbers of shipments for each state with the state-specific food transfer factors. The accident dose risks were estimated in terms of collective radiation dose to the population within 80 kilometers (50 miles).

The analysis first calculated unit risk factors for a shipment. This was done for the three types of population zones in each state and for each accident severity category. The unit risk factors were for one person per square kilometer per kilometer of route traveled. The unit risk factors were multiplied by the population densities (based on 1990 Census data) along the routes. These population densities are modeled as being within 800 meters (0.5 mile) of the routes. The accident dose risk calculation then assumed that the population density in the 800-meter band along the route is the same out to 80 kilometers (50 miles) from the route and multiplies the unit risk factor by this population density, yielding a dose risk in person-rem per kilometer of route for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The resultant dose risks (person-rem per kilometer) for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the dose risks per kilometer for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The resulting impacts were then multiplied by a scaling factor that is the ratio of the population in a state based on the 1990 Census to projected population in 2035. The results were summed to provide estimates of the accident dose risk (in person-rem) for a shipment.

Estimating Consequences of Maximum Reasonably Foreseeable Accident Scenarios

In addition to analyzing the radiological and nonradiological risks that would result from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, DOE assessed the consequences of maximum reasonably foreseeable accidents using the analysis from DIRS 152476-Sprung et al. (2000, pp. 7-30 to 7-70) for releases of material from a spent nuclear fuel cask during an accident. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur, although it could be highly unlikely. DOE concluded that, as a practical matter, events with a probability less than 1×10^{-7} (1 chance in 10 million) per year rarely need to be examined (DIRS 104601-DOE 1993, p. 28). This would be equivalent to about once in the course of 15 billion legal-weight truck shipments. For perspective, an accident this severe in commercial truck transportation would occur about once in 50 years on U.S. highways. Thus, the analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of spent nuclear fuel and high-level radioactive waste evaluated only consequences for accidents with a probability greater than 1×10^{-7} per year. The consequences were determined for atmospheric conditions that could prevail during accidents and for physical and biological pathways that would lead to exposure of members of the public and workers to radioactive materials and ionizing radiation. The analysis used the RISKIND code (DIRS 101483-Yuan et al. 1995, all) to estimate doses for individuals and populations. In addition to the accidents with a probability greater than 1×10^{-7} per year, the analysis estimated the consequences from all accident severity categories presented in DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76) for a steel-depleted uranium-steel truck cask and a steel-lead-steel rail cask. The following list describes those severity categories:

Rail Accident Descriptions

- *Case 20:* Case 20 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820ºC (1,500ºF) that burned for up to 5 days—would be similar to the conditions for a Case 20 accident.

- *Cases 19, 18, 17, and 16:* Case 19 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 18, Case 17, and Case 16 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 18, 60 to 90 miles per hour for Case 17, and 30 to 60 miles per hour for Case 16.

- *Cases 15, 12, 9, and 6:* Case 15 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 12, Case 9, and Case 6 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 12, 60 to 90 miles per hour for Case 9, and 30 to 60 miles per hour for Case 6.

- *Cases 14, 11, 8, and 5:* Case 14 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 11, Case 8, and Case 5 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 11, 60 to 90 miles per hour for Case 8, and 30 to 60 miles per hour for Case 5.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 10, Case 7, and Case 4 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4. An accident involving the impact of a jet engine from a passenger aircraft on a rail cask would be no more severe than a Case 4 accident (DIRS 157210-BSC 2001, all).

- *Cases 3, 2, and 1:* Case 3 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire. Case 2 and Case 1 are accidents that would also not involve fire but would have progressively lower impact speeds - 90 to 120 miles for Case 2 and 60 to 90 miles per hour for Case 1.

Truck Accident Descriptions

- *Case 18:* Case 18 is a long-duration (many hours), high-temperature fire that would engulf a cask. Conditions reported in the Baltimore Sun Times for the Baltimore Tunnel Fire (DIRS 156753-Ettlin 2001, all; DIRS 156754-Rascovar 2001, all), which occurred in July 2001—a fire of 820ºC (1,500ºF) that burned for up to 5 days—would be similar to the conditions for a Case 18 accident.

- *Cases 17, 16, 15, and 14:* Case 17 is a high-speed (more than 120 miles per hour) impact into a hard object such as a train locomotive severe enough to cause failure of cask seals and puncture through the cask's shield wall. The impact would be followed by a very long duration (many hours), high-temperature engulfing fire. Case 16, Case 15, and LST 14 are accidents that would also involve very long duration fires, failures of cask seals, and puncture of cask walls. However, these accidents would be progressively less severe in terms of impact speeds. The impact speeds range from 90 to 120 miles for Case 16, 60 to 90 miles per hour for Case 15, and 30 to 60 miles per hour for Case 14.

- *Cases 13, 10, 7, and 4:* Case 13 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a long duration (many hours), high-temperature engulfing fire. Case 10, Case 7, and Case 4 are also accidents that would involve long duration fires, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 10, 60 to 90 miles per hour for Case 7, and 30 to 60 miles per hour for Case 4.

- *Cases 12, 9, 6, and 3:* Case 12 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by a high-temperature engulfing fire that burned for hours. Case 9, Case 6, and Case 3 are also accidents that would involve fires that would burn for hours, and failures of cask seals. However, these accidents would be progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 9, 60 to 90 miles per hour for Case 6, and 30 to 60 miles per hour for Case 3.

- *Cases 11, 8, 5, and 2:* Case 11 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals. The impact would be followed by an engulfing fire lasting more than ½ hour up to a few hours. Case 8, Case 5, and Case 2 are accidents that would involve long duration fires, and failures of cask seals. However, these accidents are progressively less severe in terms of impact speeds ranging from 90 to 120 miles for Case 8, 60 to 90 miles per hour for Case 5, and 30 to 60 miles per hour for Case 2. An accident involving the impact of a jet engine from a passenger aircraft on a truck cask would be no more severe than any Case 11 accident (DIRS 157210-BSC 2001, all).

- *Case 1:* Case 1 is a high-speed (more than 120 miles per hour) impact into a hard surface such as granite severe enough to cause failure of cask seals—no fire.

The analysis assumed maximum reasonably foreseeable accident scenarios could occur anywhere, either in rural or urbanized areas. The probability of such an accident would depend on the amount of exposure to the transportation accident environment. In this case, exposure would be the product of the cumulative shipment distance and the applicable accident rates. However, because of large differences in exposure, principally because of the large differences in the distances traveled in the two types of population areas, a severe accident scenario that might be reasonably foreseeable in a rural area might not be reasonably foreseeable in an urbanized area. Thus, a reasonably foreseeable accident postulated to occur in a rural area (most travel would occur in rural areas), under meteorological conditions that would be exceeded (resulting in greater consequences) only 5 percent of the time, might not be reasonably foreseeable in an urbanized area where shipments would travel relatively few kilometers. Table J-22 lists the probabilities and consequences of severe rail cask accidents during national transportation based on the analysis of releases from spent fuel casks presented in DIRS 152476-Sprung et al. (2000, pp. 7-75 to 7-76) for urban

Table J-22. Frequency and consequence of rail accidents.[a]

Rail cask					
Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Urban Area - Stability Class F			Rural Area - Stability Class F		
19	7.67×10^{-19}	254,377	19	4.71×10^{-18}	419
15	7.67×10^{-16}	254,377	15	4.71×10^{-15}	419
14	5.77×10^{-15}	242,817	14	3.54×10^{-14}	400
13	2.07×10^{-13}	230,214	13	1.27×10^{-12}	379
16	2.32×10^{-12}	220,788	16	1.43×10^{-11}	364
3	2.51×10^{-11}	219,698	3	1.54×10^{-10}	361
18	9.74×10^{-17}	173,447	18	5.99×10^{-16}	285
12	9.74×10^{-14}	173,447	12	5.99×10^{-13}	285
11	7.34×10^{-13}	171,358	11	4.51×10^{-12}	282
6	6.16×10^{-10}	159,807	6	3.78×10^{-9}	264
10	2.62×10^{-11}	149,279	10	1.61×10^{-10}	246
2	3.18×10^{-9}	149,266	2	1.95×10^{-8}	245
17	1.41×10^{-15}	112,468	17	8.63×10^{-15}	185
9	1.41×10^{-12}	81,049	9	8.63×10^{-12}	134
20	2.75×10^{-7}	9,893	20	1.69×10^{-6}	16.3
8	1.05×10^{-11}	3,416	8	6.47×10^{-11}	5.63
7	3.79×10^{-10}	3,060	7	2.33×10^{-9}	5.04
1	4.59×10^{-8}	2,933	1	2.82×10^{-7}	4.83
5	4.61×10^{-9}	1,745	5	2.83×10^{-8}	2.88
4	1.66×10^{-7}	1,346	4	1.02×10^{-6}	2.22

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-75).

area and rural area population and stability class F weather conditions. Stability class D consequences were analyzed but, because the consequences are smaller than those of class F stability conditions, they are not presented. Similarly, Table J-23 lists the probabilities and consequences of severe truck accidents for stability class F conditions.

For the mostly rail scenario, legal-weight truck accidents would not be reasonably foreseeable. For rail accidents, the severity case, which is reasonably foreseeable and would have the greatest consequences, is Case 20 with an expected frequency of 2.8×10^{-7} and consequences of 9,900 person-rem.

For the mostly legal-weight truck scenario, in which only naval spent nuclear fuel would be shipped by rail, the likelihood would be less than 1×10^{-7} per year for the most severe rail accident to occur in an urbanized area. Thus, the highest severity rail accidents would only be reasonably foreseeable in rural areas under average (50-percent) meteorological conditions (probability greater than 1 in 10 million per year). For truck accidents in urban areas, the severity case, which is reasonably foreseeable and has the greatest consequences, is Case 18 with an expected frequency of 2.3×10^{-7} and consequences of 1,100 person-rem.

The analysis of maximum reasonably foreseeable accidents evaluated all the accidents for steel-depleted uranium-steel truck and steel-lead-steel rail casks from DIRS 152476-Sprung et al. (2000, pp. 7-73 and 7-76). However, only accidents from Tables J-22 and J-23 that have an expected frequency greater than 1×10^{-7} would be reasonably foreseeable.

Table J-24 summarizes the accidents with the greatest consequences that would be reasonably foreseeable. Although stability class D accidents are reasonably foreseeable, the consequences from stability class F accidents would be greater as listed in Table J-24.

Table J-23. Frequency and consequence of truck accidents.[a]

Case	Expected frequency	Total exposure (person-rem)	Case	Expected frequency	Total exposure (person-rem)
Truck cask					
Urban Area - Stability Class F			Rural Area - Stability Class F		
14	2.8×10^{-12}	36,798	14	1.6×10^{-11}	60.7
15	1.3×10^{-16}	18,919	15	7.6×10^{-16}	31.1
4	2.8×10^{-9}	8,484	4	1.6×10^{-8}	14
7	1.3×10^{-13}	5,203	7	7.6×10^{-13}	8.57
12	9.8×10^{-16}	1,251	12	5.5×10^{-15}	2.07
9	7.7×10^{-14}	1,251	9	4.4×10^{-13}	2.07
11	6.0×10^{-12}	1,146	11	3.4×10^{-11}	1.88
8	4.7×10^{-10}	1,146	8	2.7×10^{-9}	1.88
1	6.2×10^{-10}	1,125	1	3.5×10^{-9}	1.85
18	2.3×10^{-7}	1,083	18	1.3×10^{-6}	1.79
6	3.7×10^{-12}	723	6	2.1×10^{-11}	1.19
5	2.0×10^{-8}	581	5	1.1×10^{-7}	0.92
3	1.1×10^{-8}	291	3	6.4×10^{-8}	0.48
2	2.5×10^{-6}	225	2	1.4×10^{-5}	0.37
17	0	N/A[b]	17	0	N/A[b]
16	0	N/A	16	0	N/A
13	0	N/A	13	0	N/A
10	0	N/A	10	0	N/A

a. Source: DIRS 152476-Sprung et al. (2000, p. 7-74).
b. N/A = not applicable, because probability is zero.

Table J-24. Consequences (person-rem) of maximum reasonably foreseeable accidents in national transportation.[a]

Case	Urban (person-rem)	Rural (person-rem)	MEI (rem)[b]
Rail (Case 20)	9,893	16	29
Truck (Case 18)	1,083	2	3

a. All accidents are modeled in with stability class F conditions.
b. MEI = maximally exposed individual.

The analysis of consequences of maximum reasonably foreseeable accidents used data from the 1990 census escalated to 2035 to estimate the size of populations in urbanized areas that could receive exposures to radioactive materials. The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (DIRS 104800-CRWMS M&O 1999, p. 22).

The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone, where the population density would be greatest. This assumption resulted in conservative estimates of collective dose to exposed populations.

J.1.4.2.2 *Methods and Approach for Analysis of Nonradiological Impacts of Transportation Accidents*

Nonradiological accident risks are risks of traffic fatalities. Traffic fatality rates are reported by state and Federal transportation departments as fatalities per highway vehicle- or train-kilometer traveled. The fatalities are caused by physical trauma in accidents. For nonradiological accident risks estimated in this

EIS for legal-weight truck transportation, accident fatality risks were based on state-level fatality rates for Interstate Highways (DIRS 103455-Saricks and Tompkins 1999, all). Accident fatality risks for rail transportation were also calculated using state-specific rates (DIRS 103455-Saricks and Tompkins 1999, all). Section J.2.2 discusses methods and data used to analyze accidents for barge transportation.

For truck transportation, the rates in DIRS 103455-Saricks and Tompkins (1999, Table 4) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are multiaxle tractor-trailer trucks having a tractor and one to three freight trailers connected to each other. This kind of truck with a single trailer would be used to ship spent nuclear fuel and high-level radioactive waste. Truck accident rates were determined for each state based on statistics compiled by the U.S. Department of Transportation Office of Motor Carriers for 1994 through 1996. The report presents accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities include crew members and all others attributed to accidents. Although escort vehicles would not be heavy combination trucks, the fatality rate data used for truck shipments of loaded and empty spent fuel casks were also used to estimate fatalities from accidents that would involve escort vehicles.

Rail accident rates were computed and presented similarly to truck accident rates, but a railcar is the unit of haulage. The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1994 through 1996. Rail accident rates include both mainline accidents and those occurring in railyards. The per-railcar rate in DIRS 103455-Saricks and Tompkins (1999, Table 6) was multiplied by 4.2, the average number of railcars involved in an accident.

The accident rates used to estimate traffic fatalities were computed using data for all interstate shipments, independent of the cargoes. Shippers and carriers of radioactive material generally have a higher-than-average awareness of transport risk and prepare cargoes and drivers accordingly (DIRS 101920-Saricks and Kvitek 1994, all). These effects were not given credit in the assessment.

J.1.4.2.3 *Data Used To Estimate Incident Rates for Rail and Motor Carrier Accidents*

In analyzing potential impacts of transporting spent nuclear fuel and high-level radioactive waste, DOE considered both incident-free transportation and transportation accidents. Potential incident-free transportation impacts would include those caused by exposing the public and workers to low levels of radiation and other hazards associated with the normal movement of spent nuclear fuel and high-level radioactive waste by truck, rail, or barge. Impacts from accidents would be those that could result from exposing the public and workers to radiation, as well as vehicle-related fatalities.

In its analysis of impacts from transportation accidents, DOE relied on data collected by the U.S. Department of Transportation and others (for example, the American Petroleum Institute) to develop estimates of accident likelihood and their ranges of severity (DIRS 101828-Fischer et al. 1987, pp. 7-25 and 7-26). Using these data, the analysis estimated that as many as 66 accidents could occur over 24 years in the course of shipping spent nuclear fuel to the repository by legal-weight trucks; 8 rail accidents that involved a railcar carrying a cask could occur if most shipments were by rail; and no accidents would be likely for the limited use of barges.

Furthermore, in using data collected by the U.S. Department of Transportation, the analysis considered the range of accidents, from slightly more than “fender benders” to high-speed crashes, that the DOE carrier would have to report in accordance with the requirements of U.S. Department of Transportation regulations. The accidents that could occur would be unlikely to be severe enough to affect the integrity of the shipping casks.

The following paragraphs discuss reporting and definitions for transportation accidents and the relationships of these to data used in analyzing transportation impacts in this EIS.

J.1.4.2.3.1 Transportation Accident Reporting and Definitions. In the United States, the reporting of transportation accidents and incidents involving trucks, railroads, and barges follows requirements specified in various Federal and state regulations.

Motor Carrier Accident Reporting and Definitions

Regulations generally require the reporting of motor carrier accidents (regardless of the cargo being carried) if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a functional threshold for damage to vehicles rather than a value-of-damage threshold, which was used until the 1980s. Nonetheless, many states continue to use value thresholds (for example, Ohio uses $500) for vehicle damage when documenting reportable accidents.

Until March 4, 1993, Federal regulations (49 CFR Part 394) required motor carriers to submit accident reports to the Federal Highway Administration Motor Carrier Management Information System using the so-called “50-T” reporting format. The master file compiled from the data on these reports in the Federal Highway Administration Office of Motor Carriers was the basis of accident, fatality, and injury rates developed for the 1994 study of transportation accident rates (DIRS 101920-Saricks and Kvitek 1994, all).

The Final Rule (58 *FR* 6726; February 2, 1993) modified the carrier reporting requirement; rather than submitting reports, carriers now must maintain a register of accidents that meet the definition of an accident for 1 year after such an accident occurs. Carriers must make the contents of such a register available to Federal Highway Administration agents investigating specific accidents. They must also give “…all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question of inquiry” to determine if hazardous materials other than spilled fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports (49 CFR 390.15). The reason for this rule change was the emergence of an automated State accident reporting system compiled from law enforcement accident reports that, pursuant to provisions of the Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240, 105 Stat. 1914), was established under the Motor Carrier Safety Assistance Program.

Under Section 408 of Title IV of the Motor Carrier Act of 1991 (Public Law 102-240, 105 Stat. 2140), a component of the Intermodal Surface Transportation Efficiency Act, the Secretary of Transportation is authorized to make grants to states to help them achieve uniform implementation of the police reporting system for truck and bus accidents recommended by the National Governors Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions. They are entered in a Federally maintained SAFETYNET database on approximately a weekly basis. The SAFETYNET database, in turn, is compiled and managed as part of the Motor Carrier Management Information System.

Because DIRS 152476-Sprung et al. (2000, all) is the fundamental source for data that describes the severity of transportation accidents used in this EIS, the relative constancy of the definition of *accident* is important in establishing confidence in estimated impact results. Thus, although the transportation environment has changed over the 40 years of data collection, the constancy of the definition of *accident* tends to provide confidence that the distribution of severity for reported accidents has remained relatively the same. That is, low-consequence, fender-bender accidents are the most common, high-consequence, highly energetic accidents are rare, and the proportions of these have remained roughly the same.

COMMERCIAL MOTOR VEHICLE ACCIDENT
(49 CFR 390.5)

An occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in:

- A fatality
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle to be transported away from the scene by a tow truck or other motor vehicle

The term accident does not include:

- An occurrence involving only boarding and alighting from a stationary motor vehicle
- An occurrence involving only the loading or unloading of cargo
- An occurrence in the course of the operation of a passenger car or a multipurpose passenger vehicle by a motor carrier and is not transporting passengers for hire or hazardous materials of a type and quantity that require the motor vehicle to be marked or placarded in accordance with 49 CFR 177, Subpart 823

Changes in the transportation environment, such as changes in speed limits and safety technology, tend to change the accident rate (accidents per vehicle-kilometer of travel). Overall, however, given that the definition of *accident* does not change, such changes do not greatly affect the distribution of accident severities. For example, recent increases in speed limits from 105 to 121 kilometers (65 to 75 miles) per hour represent about a 25-percent increase in the maximum mechanical energy of vehicles. Other information aside, this increase could lead to the conclusion that the resulting distribution of accidents would show an increase for the most severe accidents in comparison to minor accidents. However, the speed limit increases do not represent a corresponding increase in actual traffic speeds, and would be unlikely to change the distribution of velocities and, thus, mechanical energies, of severe accidents from those reported in DIRS 152476-Sprung et al. (2000, all), which ranged to faster than 193 kilometers (120 miles) per hour.

Rail Carrier Accident Reporting and Definitions

As with regulations governing the reporting of motor carrier accidents, Federal Railroad Administration regulations generally require the reporting of accidents if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a value-based reporting threshold for damage to vehicles; the value has been indexed to inflation since 1975.

Rail carriers covered by these requirements must fulfill several bookkeeping tasks. The Federal Railroad Administration requires the submittal of a monthly status report, even if there were no reportable events during the period. This report must include accidents and incidents, and certain types of incidents require immediate telephone notification. Logs of reportable injuries and on-track incidents must be maintained by the railroads on which they occur, and a listing of such events must be posted and made available to employees and to the Federal Railroad Administration, along with required records and reports, on request. The data entries extracted from the reporting format are consolidated into an accident/incident database that separates reportable *accidents* from grade-crossing *incidents*. These are processed annually into event, fatality, and injury count tables in the Federal Railroad Administration's *Accident/Incident Bulletin* (DIRS 103455-Saricks and Tompkins 1999, all), which the Office of Safety publishes on the Internet (*safetydata.fra.dot.gov/officeofsafety*).

RAILROAD ACCIDENT/INCIDENT
(49 CFR 225.11)

- An impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle or pedestrian at a highway-rail grade crossing

- A collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in reportable damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed

- An event arising from the operation of a railroad which results in:
  - Death to any person
  - Injury to any person that requires medical treatment
  - Injury to a railroad employee that results in:
    - A day away from work
    - Restricted work activity or job transfer
    - Loss of consciousness
    - Occupational illness

In contrast to the regulations for motor carriers discussed above, the Federal Railroad Administration regulations cited above call for the reporting of accidents and incidents. The Administration defines an *accident* as "an event involving on-track railroad equipment that results in damage to the railroad on-track equipment, signals, track, or track structure, and roadbed at or exceeding the dollar damage threshold" (49 CFR 225.11). Train *incidents* are defined as "events involving on-track railroad equipment [and non-train incidents arising from the operation of a railroad] that result in the reportable death and/or injury or illness of one or more persons, but do not result in damage at or beyond the damage threshold" (49 CFR 225.11). Because damage to casks containing spent nuclear fuel will necessarily involve severe accidents (hence, substantial damage), DIRS 152476-Sprung et al. (2000, all) used only train accidents to form the basis for developing the conditional probabilities of accident severities.

As with motor carrier operations, the constancy of the definition of a train accident is important in establishing confidence in the impact. For rail accidents the transportation environment has not changed dramatically over the years of data collection, and the definition of *accident* has remained essentially unchanged (with adjustments for inflation). The constancy of the definition provides confidence that the distribution of severity for reported accidents has remained relatively the same—low-consequence, limited-damage accidents are the most common and high-consequence, highly energetic accidents are rare, and their proportions have remained about the same. Changes in the rail transportation environment, as in safety and operations technology (for example, shelf-type couplers and tankcar head protection), have resulted in lower accident rates (per railcar-kilometer of travel) and, in some cases, less severe accidents. However, because the definition of *accident* has not changed appreciably, the changes that have occurred are not the kind that would greatly affect the relative proportions of minor and severe accidents.

Reporting and Definitions for Marine Casualties and Incidents

As with the regulations governing the reporting of motor carrier and rail accidents, U.S. law (46 U.S.C. 6101 to 6103) requires operators to report marine casualties and incidents if there are injuries, fatalities, or property damage. In addition, the law requires the reporting of significant harm to the environment.

MARINE CASUALTY AND INCIDENT
(46 U.S.C. 6101 to 6103)

Criteria have been established for the required reporting (by vessel operators and owners) of marine casualties and incidents involving all United States flag vessels occurring anywhere in the world and any foreign flag vessel operating on waters subject to the jurisdiction of the United States. An incident must be reported within five days if it results in:

- The death of an individual
- Serious injury to an individual
- "Material" loss of property (threshold not specified; previously was $25,000)
- Material damage affecting the seaworthiness or efficiency of the vessel
- Significant harm to the environment

The states collect casualty data for incidents occurring in navigable waterways within their borders, and there is a uniform state marine casualty reporting system for transmitting these reports to Federal jurisdiction (the U.S. Coast Guard). Coast Guard Headquarters receives quarterly extracts of the Marine Safety Information System developed from these sources. This system is a network database into which Coast Guard investigators enter cases at each marine safety unit. The analysis uses a Relational Database Management System. The Coast Guard Office of Investigations and Analysis compiles and processes the casualty reports into the formats and partitioned data sets that comprise the Marine Safety Information System database, which includes maritime accidents, fatalities, injuries, and pollution spills dating to 1941 (however, the file is complete only from about 1991 to the present).

Hazardous Material Transportation Accident and Incident Reporting and Definitions

Radioactive material is a subset of the more general term *hazardous material*, which includes commodities such as gasoline and chemical products. The U.S. Department of Transportation Office of Hazardous Materials estimates that there are more than 800,000 hazardous materials shipments per day, of which about 7,700 shipments contain radioactive materials.

Hazardous materials transportation regulations (49 CFR 171) contain no distinction between an *accident* and an *incident*, and *incident* is the term used to describe situations that must be reported. Hazardous materials regulations (49 CFR 171.15) require the reporting of incidents if:

- A person is killed
- A person receives injuries requiring hospitalization
- The estimated property damage is greater than $50,000
- An evacuation of the public occurs lasting one or more hours
- One or more major transportation arteries are closed or shutdown for one or more hours
- The operational flight pattern or routine of an aircraft is altered
- Fire, breakage, spillage, or suspected radioactive contamination occurs involving shipment of radioactive material
- Fire, breakage, spillage, or suspected contamination occurs involving shipment of infectious agents

- There has been a release of a marine pollutant in a quantity exceeding 450 liters (about 120 gallons) for liquids or 400 kilograms (about 880 pounds) for solids

- There is a situation that, in the judgement of the carrier, should be reported to the U.S. Department of Transportation even though it does not meet the above criteria

These criteria apply to loading, unloading, and temporary storage, as well as to transportation. The criteria involving infectious agents or aircraft are unlikely to be used for spent nuclear fuel or high-level radioactive waste shipments. Based on these criteria, reportable motor vehicle and rail transportation situations are far more exclusionary than hazardous material situations.

Carriers (not law enforcement officials) are required to report hazardous materials incidents to the U.S. Department of Transportation. These reports are compiled in the Hazardous Materials Incident Report database. In addition, U.S. Nuclear Regulatory Commission regulations (10 CFR 20.2201, 20.2202, 20.2203) require the reporting of a loss of radioactive materials, exposure to radiation, or release of radioactive materials.

Sandia National Laboratories maintains the Radioactive Materials Incident Report database, which contains incident reports from the Hazardous Materials Incident Report database that involve radioactive material. In addition, the Radioactive Materials Incident Report database contains data from the U.S. Nuclear Regulatory Commission, state radiation control offices, the DOE Unusual Occurrence Report database, and media coverage of radioactive materials transportation incidents. DIRS 101802-DOE (1995, Volume 1, Appendix I, pp. I-117) and DIRS 102172-McClure and Fagan (1998, all) discuss historic incidents involving spent nuclear fuel that are reported in the Radioactive Materials Incident Report database as well as incidents that took place prior to the existence of this database. The database characterizes incidents in three categories: transportation accidents, handling accidents, and reported incidents. However, the definitions of these categories are not consistent with the definitions used in other U.S. Department of Transportation databases. For example, from 1971 through 1998, the Radioactive Materials Incident Report database lists one transportation accident involving a loaded rail shipment of spent nuclear fuel. However, based on current Federal Railroad Administration reporting requirements, this occurrence probably would be listed as a grade-crossing incident, not an accident. For this reason and because of the small number of occurrences in the database involving spent nuclear fuel, the EIS analysis did not use the Radioactive Materials Incident Report database to estimate transportation accident rates.

J.1.4.2.3.2 Accident Rates for Transportation by Heavy-Combination Truck, Railcar, and Barge in the United States. DIRS 103455-Saricks and Tompkins (1999, all) developed estimates of accident rates for heavy-combination trucks, railcars, and barges based on data available for 1994 through 1996. The estimates provide an update for accident rates published in 1994 (DIRS 101920-Saricks and Kvitek 1994, all) that reflected rates from almost a decade earlier.

Rates for Accidents in Interstate Commerce for Heavy-Combination Trucks

DIRS 103455-Saricks and Tompkins (1999, all) developed basic descriptive statistics for state-specific rates of accidents involving interstate-registered combination trucks for 1994, 1995, and 1996. The accident rate over all road types for 1994 was 2.98×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3a); for 1995 it was 2.97×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3b); and for 1996 it was 3.46×10^{-7} accident per truck-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 3c). The composite mean from 1994 through 1996 was 3.21×10^{-7} accident per truck-kilometer.

During the 24 years of the Proposed Action, the *mostly legal-weight truck* national transportation scenario would involve about 53,000 truck shipments of spent nuclear fuel and high-level radioactive waste.

Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 4), the transportation analysis estimated that those shipments could involve as many as 66 accidents. During the same period, the *mostly rail* scenario would involve about 1,100 truck shipments, and the analysis estimated that as many as one truck accident could occur during these shipments. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the casks, and would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask.

Rates for Freight Railcar Accidents

Results for accident rates for freight railcar shipments from DIRS 103455-Saricks and Tompkins (1999, all), show that domestic rail freight accidents, fatalities, and injuries on Class 1 and 2 railroads have remained stable or declined slightly since the late 1980s. Based on data from 1994 through 1996, these rates are 5.39×10^{-8}, 8.64×10^{-8}, and 1.05×10^{-8} per railcar-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 6). This conclusion is based on applying denominators that do *not* include train and car kilometers for intermodal shipments (containers and trailers-on-flatcar) not loaded by the carriers themselves. Thus, the actual denominators are probably higher and the rates consequently lower, by about 20 percent.

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario would involve as many as 10,000 rail shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in DIRS 103455-Saricks and Tompkins (1999, Table 6), the analysis estimated that these shipments could involve eight accidents. More than 99.99 percent of these accidents would not generate forces capable of causing functional damage to the cask; these accidents would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask. For the *mostly legal-weight truck* scenario, rail accidents would be unlikely during the 300 railcar shipments of naval spent nuclear fuel.

Rates for Barge Accidents

Waterway results show a general improvement over mid-1980s rates. The respective rates for 450-metric-ton (500-ton) shipments for waters internal to the coast (rivers, lakes, canals, etc.) for accident and incident involvements and fatalities were 1.68×10^{-6} and 8.76×10^{-9} per shipment-kilometer, respectively (DIRS 103455-Saricks and Tompkins 1999, Table 8b). Rates for lake shipping were lower—2.58×10^{-7} and 0 per shipment-kilometer, for accidents and incidents and for fatalities, respectively. Coastal casualty involvement rates have risen in comparison to the data recorded about 10 years ago, and are comparable to rates for internal waters—5.29×10^{-7} and 8.76×10^{-9} per shipment-kilometer (DIRS 103455-Saricks and Tompkins 1999, Table 9b).

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario could involve the use of barges to ship spent nuclear fuel from 17 commercial sites. Based on the data in DIRS 103455-Saricks and Tompkins (1999, all), the analysis estimated that less than one accident could occur during such shipments. A barge accident severe enough to cause measurable damage to a shipping cask would be highly unlikely.

Rates for Safe Secure Trailer Accidents

DOE uses safe secure trailers to transport hazardous cargoes in the continental United States. The criteria used for reporting accidents involving these trailers are damage in excess of $500, a fire, a fatality, or damage sufficient for the trailer to be towed. From 1975 through 1998, 14 accidents involved safe secure trailers over about 54 million kilometers (about 34 million miles) of travel, which yields a rate of 2.6×10^{-7} accident per kilometer (4.2×10^{-7} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4) for heavy combination trucks, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile).

J.1.4.2.3.3 Accident Data Provided by the States of Nevada, California, South Carolina, Illinois, and Nebraska. In May 1998, DOE requested the 48 contiguous states to provide truck and rail transportation accident data for use in this EIS. Five states responded – Nevada, California, Illinois, Nebraska, and South Carolina (DIRS 104728-Denison 1998, all; DIRS 103709-Caltrans 1997, all; DIRS 104801-Wort 1998, all; DIRS 104783-Kohles 1998, all; DIRS 103725-SCDPS 1997, all). No states provided rail information.

- *Nevada.* Nevada provided a highway accident rate of 1.1×10^{-6} accident per kilometer (1.8×10^{-6} per mile) for interstate carriers over all road types. This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4); 2.5×10^{-7} accident per kilometer (3.9×10^{-7} per mile) for heavy trucks over all road types in Nevada from 1994 to 1996.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Nevada the accident criteria are fatality, injury, or $750 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.1×10^{-6} to about 4.1×10^{-7} accident per kilometer (1.8×10^{-6} to 6.7×10^{-7} per mile). The radiological accident risk in Nevada for the mostly legal-weight truck scenario would increase over 24 years from 0.0002 latent cancer fatality to about 0.0005 latent cancer fatality (a likelihood of 5 in 10,000 of one latent cancer fatality) if the accident rate reported by DIRS 103455-Saricks and Tompkins (1999, p. 33) for Nevada were replaced by the rate of 4.1×10^{-7} per kilometer. Thus, the impacts of the rate for accidents involving large trucks on Nevada highways reported by Nevada (DIRS 104728-Denison 1998, all) would be comparable to the impacts derived using the rate estimated by DIRS 103455-Saricks and Tompkins (1999, p. 33).

- *California.* California responded with highway accident rates that included all vehicles (cars, buses, and trucks). The accident rate for Interstate highways was 4.2×10^{-7} accident per kilometer (6.8×10^{-7} per mile) for all vehicles in 1996. This rate is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer (2.6×10^{-7} per mile) for heavy trucks on California interstate highways from 1994 to 1996.

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in California the accident criteria are fatality, injury, or $500 property damage. Based on national data from DIRS 103721-FHWA (1997, p. 2) and DIRS 102231-FHWA (1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 4.2×10^{-7} to about 1.6×10^{-7} accident per kilometer (6.8×10^{-7} to 2.6×10^{-7} per mile). In addition, the rate provided by California was for all vehicles. Based on national data from the U.S. Department of Transportation Bureau of Transportation Statistics, using the accident rate for large trucks would reduce the all-vehicle accident rate from 1.6×10^{-7} to about 1.3×10^{-7} accident per kilometer (2.6×10^{-7} to 2.1×10^{-7} per mile) for large trucks. This rate is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer.

- *Illinois.* Illinois provided highway data for semi-trucks from 1991 through 1995 over all road types. Over this period, the accident rate was 1.8×10^{-6} accident per kilometer (2.9×10^{-6} per mile). From 1994 through 1996, DIRS 103455-Saricks and Tompkins (1999, all) estimated an accident rate of 3.0×10^{-7} accident per kilometer (4.8×10^{-7} per mile) for heavy trucks over all road types in Illinois.

  The definition of *accident* used in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in Illinois the accident criteria are fatality, injury, or $500 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition would reduce the accident rate from 1.8×10^{-6} to about 6.7×10^{-7} accident per kilometer (2.9×10^{-6} to 1.1×10^{-6} per mile). This rate is comparable to the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all).

- *Nebraska.* Nebraska provided a highway accident rate of 2.4×10^{-7} accident per kilometer (3.8×10^{-7} per mile) for 1997. Nebraska did not specify if the rate was for interstate highways, but it is for interstate truck carriers. This rate is slightly less than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) for Nebraska interstates, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile) for heavy trucks from 1994 through 1996.

- *South Carolina.* South Carolina responded with highway accident rates that included all types of tractor/trailers (for example, mobile homes, semi-trailers, utility trailers, farm trailers, trailers with boats, camper trailers, towed motor homes, petroleum tankers, lowboy trailers, auto carrier trailers, flatbed trailers, and twin trailers). The rate was 8.3×10^{-7} accident per kilometer (1.3×10^{-6} per mile), for all road types. [This is higher than the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile) for heavy trucks on all road types in South Carolina from 1994 through 1996].

  The definition of *accident* in DIRS 103455-Saricks and Tompkins (1999, p. 4) is the Federal definition (fatality, injury, or tow-away); in South Carolina the accident criteria are fatality, injury, or $1,000 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (DIRS 103721-FHWA 1997, p. 2; DIRS 102231-FHWA 1998, pp. 1 and 2), using the Federal definition of an accident would reduce the accident rate from 8.3×10^{-7} to about 3.1×10^{-7} accident per kilometer (1.3×10^{-6} to 5.0×10^{-7} per mile), which is slightly less than the rate estimated by DIRS 103455-Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile). In addition, the accident rate estimated by DIRS 103455-Saricks and Tompkins (1999, all) was based on Motor Carrier Management Information System vehicle configuration codes 4 through 8 (truck/trailer, bobtail, tractor/semi-trailer, tractor/double, and tractor/triple), while the rate obtained from South Carolina included all truck/trailer combinations. Including all of the combinations tends to increase accident rates; for example, light trucks have higher accident rates than heavy trucks (DIRS 148081-BTS 1999, Table 3-22).

DOE evaluated the effect of using the data provided by the five states on radiological accident risk for the mostly legal-weight truck national transportation scenario. If the data used in the analysis for the five states (DIRS 103455-Saricks and Tompkins 1999, Table 4) were replaced by the data provided by the states with the adjustments discussed, the change in the resulting estimate of radiological accident risk would be small, increasing from 0.067 to 0.071 latent cancer fatality. Using the unadjusted data provided by those states would result in an increase in accident risk from 0.067 to 0.093 latent cancer fatality.

J.1.4.2.4 *Transportation Accidents Involving Nonradioactive Hazardous Materials*

The analysis of impacts of transportation accidents involving the transport of nonradioactive hazardous materials to and from Yucca Mountain used information presented in two U.S. Department of Transportation reports (DIRS 103718-DOT 1998, Table 1; DIRS 103708-BTS 1996, p. 43) on the annual number of hazardous materials shipments in the United States and the number of deaths caused by hazardous cargoes in 1995. In total, there are about 300 million annual shipments of hazardous materials; only a small fraction involve radioactive materials. In 1995, 6 fatalities occurred because of hazardous cargoes. These data suggest a rate of 2 fatalities per 100 million shipments of hazardous materials. DOE anticipates about 40,000 shipments of nonradioactive hazardous materials (including diesel fuel and laboratory and industrial chemicals) to and from the Yucca Mountain site during construction, operation and monitoring, and closure of the repository. Assuming that the rate for fatalities applies to the transportation of nonradioactive hazardous materials to and from Yucca Mountain, DOE does not expect fatalities from 40,000 shipments of these materials.

J.1.4.2.5 *Cost of Cleanup and Ecological Restoration Following a Transportation Accident*

Cost of Cleanup. According to the Nuclear Regulatory Commission report *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76), in more than 99.99 percent of accidents radioactive material would not be released from the cask. After initial safety precautions had been taken, the cask would be recovered and removed from the accident scene. Because no radioactive material would be released, based on reported experience with two previous accidents (DIRS 156110-FEMA 2000, Appendix G, Case 4 and Case 5), the economic costs of these accidents would be minimal.

For the 0.01 percent of accidents severe enough to cause a release of radioactive material from a cask, a number of interrelated factors would affect costs of cleaning up resulting radioactive contamination after the accident. Included are: the severity of the accident and the initial level of contamination; the weather at the time and following; the location and size of the affected land area and how the land is used; the standard established for the allowable level of residual contamination following cleanup and the decontamination method used; and the technical requirements for and location for disposal of contaminated materials.

Because it would be necessary to specify each of the factors to estimate clean up costs, any estimate for a single accident would be highly uncertain and speculative. Nonetheless, to provide a gauge of the costs that could be incurred DOE examined past studies of costs of cleanup following hypothetical accidents that would involve uncontrolled releases of radioactive materials.

A study of the impacts of transporting radioactive materials conducted by the Nuclear Regulatory Commission in 1977 estimated that costs could range from about $1 million to $100 million for a transportation accident that involved a 600-curie release of a long-lived radionuclide (DIRS 101892-NRC 1977, Table 5-11). These estimates would be about 3 times higher if escalated for inflation from 1977 to the present. In 1980 DIRS 155054-Finley et al. (1980, Table 6-9) estimated that costs could range from about $90 million to $2 billion for a severe spent nuclear fuel transportation accident in an urban area. DIRS 154814-Sandquist et al. (1985, Table 3-7) estimated that costs could range from about $200,000 to $620 million. In this study, Sandquist estimated that contamination would affect between 0.063 to 4.3 square kilometers (16 to 1,100 acres). A study by DIRS 152083-Chanin and Murfin (1996, Chapter 6) estimated the costs of cleanup following a transportation accident in which plutonium would be dispersed. This study developed cost estimates for cleaning up and remediating farmland, urban areas, rangeland, and forests. The estimates ranged from $38 million to $400 million per square kilometer that would need to be cleaned up. The study also evaluated the costs of expedited cleanups in urban areas for light, moderate, and heavy contamination levels. These estimates ranged from $89 million to $400 million per square kilometer.

The National Aeronautics and Space Administration studied potential accidents for the Cassini mission, which used a plutonium powered electricity generator. The Agency estimated that costs of cleaning up radioactive material contamination on land following potential launch and reentry accidents. The estimate for the cost following a launch accident ranged from $7 million to $70 million (DIRS 155551-NASA 1995, Chapter 4) with an estimated contaminated land area of about 1.4 square kilometers (350 acres). The Agency assumed cleanup costs would be $5 million per square kilometer if removal and disposal of contaminated soil were not required and $50 million per square kilometer if those activities were required. For a reentry accident that would occur over land, the study estimated that the contaminated land area could range from about 1,500 to 5,700 square kilometers (370,000 to 1.4 million acres) (DIRS 155551-NASA 1995, Chapter 4) with cleanup costs possibly exceeding a total of $10 billion. In a more recent study of potential consequences of accidents that could involve the Cassini mission, NASA estimated that costs could range from $7.5 million to $1 billion (DIRS 155550-NASA 1997, Chapter 4). The contaminated land area associated with these costs ranged from 1.5 to 20 square kilometers (370 to 4,900 acres). As in the 1995 study, these estimates were based on cleanup costs in the range of $5 million to $50 million per square kilometer.

Using only the estimates provided by these studies, the costs of cleanup following a severe transportation accident involving spent nuclear fuel where radioactive material was released could be in the range from $300,000 (after adjusting for inflation from 1985 to the present) to $10 billion. Among the reasons for this wide range are different assumptions made regarding the factors that must be considered: 1) the severity of the assumed accident and resulting contamination levels, 2) accident location and use of affected land areas, 3) meteorological conditions, 4) cleanup levels and decontamination methods, and 5) disposal of contaminated materials. However, the extreme high estimates of costs are based on assumptions that all factors combine in the most disadvantageous way to create a "worst case." Such worst cases are not reasonably foreseeable. Conversely, estimates as low as $300,000 may also not be realistic for all of the direct and indirect costs of cleaning up following an accident severe enough to cause a release of radioactive materials.

To gauge the range of costs that it could expect for severe accidents in transporting spent nuclear fuel to a Yucca Mountain repository, DOE considered the spectrum of accidents that are reasonably foreseeable (see Section J.1.4.2.1) and the amount of radioactive material that could be released in each such accident and compared this to the estimates of releases used by the various studies discussed above. Based on 2 million curies of radioactive material in a rail casks loaded with spent nuclear fuel, about 13 curies (mostly cesium) would be released in a maximum reasonably foreseeable accident. This is about 100 times less than used by Sandquist in his study (1,630 curies) and 50 times less than the release used in the estimates provided by the Nuclear Regulatory Commission in 1977 (600 curies). The estimated frequency for an accident this severe to occur is about 3 times in 10 million years. Based on the prior studies (where estimated releases exceeded those estimated in this appendix for a maximum reasonably foreseeable accident) and the amount of radioactive material that could be released in a maximum reasonably foreseeable accident, the Department believes that the cost of cleaning up following such an accident could be a few million dollars. Nonetheless, as stated above, the Department also believes that estimates of such costs contain great uncertainty and are speculative; they could be less or 10 times greater depending on the contributing factors.

For perspective, the current insured limit of responsibility for an accident involving releases of radioactive materials to the environment is $9.43 billion (see Appendix M). The annual cost of transporting spent nuclear fuel and high-level radioactive waste to Yucca Mountain would be about $200 million.

Ecological Restoration. Following a severe transportation accident, it might be necessary to restore the ecology of an area after the area was remediated. DIRS 152083-Chanin and Murfin (1996, all) present a review of the scope of ecological restoration that can be accomplished and the requirements that would apply in the event of an accident where environmental damage resulting from cleaning up radioactive material contamination would in turn result in a need for environmental restoration. The restoration that would be necessary following an accident cannot be predicted. It would depend on the environmental factors involved—1) the levels of contamination from the accident, 2) cleanup levels and decontamination methods used, and 3) location and ecology of the affected land areas—and the restoration goal that was used. DIRS 152083-Chanin and Murfin (1996, Chapter 6) observe

> "*[a] long-standing definition of the preferred goal of site restoration is to establish an ecological community as similar as possible to that which existed before an accident. Alternative goals are to*

establish a similar, but not identical, community; to establish an entirely different but valued community; or, if none of the foregoing is feasible, to establish some less-valued community."

The costs discussed above include costs for environmental restoration.

DIRS 152083-Chanin and Murfin (1996, all) provide the following assessments of environmental restoration that could be accomplished following clean up of contamination from an accident.

- Unassisted restoration of desert land is difficult, but assisted restoration can be very successful.
- Grasslands may be restored naturally provided only limited soil has been removed. Assisted restoration of prairies is also successful.
- Total restoration of forests may not be possible if the area is too large for natural reseeding; an alternative use may have to be found for forestland.
- Restoration of farmland is relatively simple.
- Restoration of urban land to building sites is simple.
- Restoration to parkland is possible, but more costly.

J.2 Evaluation of Rail and Intermodal Transportation

DOE could use several modes of transportation to ship spent nuclear fuel from the 72 commercial and 5 DOE sites. Legal-weight trucks could transport spent nuclear fuel and high-level radioactive waste in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, railcars could be used to ship rail casks directly to the Yucca Mountain site, if a branch rail line was built in Nevada, or to an intermodal transfer station in Nevada if heavy-haul trucks were used. Rail casks would weigh as much as 136,000 kilograms (150 tons).

For sites that have the capability to load rail casks but are not served by a railroad, DOE could use heavy-haul trucks or, for sites on navigable waterways, barges to transport casks to nearby railheads.

For rail shipments, DOE could request the railroads to provide dedicated trains to transport casks from the sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

In addition, DOE evaluated the potential for including two other scenarios: (1) a different mostly rail scenario in which railcars would transport legal-weight truck casks and (2) a large-scale barge scenario.

J.2.1 LEGAL-WEIGHT TRUCK CASKS ON RAILCARS SCENARIO

DOE assessed the sensitivity of transportation impacts to assumptions related to transportation scenarios. The analysis evaluated a variation of the mostly rail scenario in which shipments would be made using casks much smaller than rail casks—legal-weight truck casks—shipped to Nevada on railcars then transported on legal-weight trucks from a rail siding to Yucca Mountain. Under this scenario, because all shipments (except shipments of naval spent nuclear fuel) would use legal-weight truck casks, the number of railcar shipments would be about 53,000 over the 24 years of the Proposed Action. This would be the same as the number of legal-weight truck plus naval spent nuclear fuel shipments in the mostly legal-weight truck scenario.

> *establish a similar, but not identical, community; to establish an entirely different but valued community; or, if none of the foregoing is feasible, to establish some less-valued community."*

The costs discussed above include costs for environmental restoration.

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J.2 Evaluation of Rail and Intermodal Transportation

DOE could use several modes of transportation to ship spent nuclear fuel from the 72 commercial and 5 DOE sites. Legal-weight trucks could transport spent nuclear fuel and high-level radioactive waste in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, railcars could be used to ship rail casks directly to the Yucca Mountain site, if a branch rail line was built in Nevada, or to an intermodal transfer station in Nevada if heavy-haul trucks were used. Rail casks would weigh as much as 136,000 kilograms (150 tons).

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For rail shipments, DOE could request the railroads to provide dedicated trains to transport casks from the sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

In addition, DOE evaluated the potential for including two other scenarios: (1) a different mostly rail scenario in which railcars would transport legal-weight truck casks and (2) a large-scale barge scenario.

J.2.1 LEGAL-WEIGHT TRUCK CASKS ON RAILCARS SCENARIO

DOE assessed the sensitivity of transportation impacts to assumptions related to transportation scenarios. The analysis evaluated a variation of the mostly rail scenario in which shipments would be made using casks much smaller than rail casks—legal-weight truck casks—shipped to Nevada on railcars then transported on legal-weight trucks from a rail siding to Yucca Mountain. Under this scenario, because all shipments (except shipments of naval spent nuclear fuel) would use legal-weight truck casks, the number of railcar shipments would be about 53,000 over the 24 years of the Proposed Action. This would be the same as the number of legal-weight truck plus naval spent nuclear fuel shipments in the mostly legal-weight truck scenario.

DOE estimated impacts of this variation of the mostly rail transportation scenario by scaling from the impacts estimated for the mostly rail scenario. The analysis used the ratio of the number of railcars that would be shipped to the number of railcar shipments estimated for the mostly rail scenario and assumed each shipment would include an escort car and five railcars carrying legal-weight truck casks. The estimated number of public incident-free latent cancer fatalities would be approximately 4, and the estimated number of traffic fatalities would be 8. The total of these estimates, 12, is about 1.5 times the DOE revised estimate of a total of 7 fatalities (2.5 latent cancer fatalities plus 4.5 traffic fatalities) for the legal-weight truck scenario.

DOE determined that while this scenario would be feasible, it would not be practical. The number of shipping casks and railcar shipments would be greater by a factor of 5 than for the mostly rail scenario and the additional cost to the Program would be more than $1 billion. In addition, the truck-casks-on-railcars scenario would lead to the highest estimates of occupational health and public health and safety impacts, most coming from rail-traffic related facilities.

J.2.2 LARGE-SCALE BARGE SCENARIO

In response to public comments on the 1986 Environmental Assessment for the Yucca Mountain Site, Research and Development Area, Nevada (DIRS 104731-DOE 1986, p. C.2-40), DOE described barge transportation as a feasible alternative that could play a secondary or supplementary role in the transportation of radioactive wastes to a repository. In the Final Environmental Impact Statement on Management of Commercially Generated Radioactive Waste (DIRS 104832-DOE 1980, Volume A, pp. 4.64 and 4.65), DOE concluded that barge transport is an alternative when both the nuclear powerplant and the encapsulation or storage facility are on navigable waterways. That EIS observed that barge transport suggests high payloads and low tariffs, but cost gains in these two areas could be offset by the longer estimated transit times for barge shipments. The EIS also observed that casks for barge shipment of spent nuclear fuel probably would be similar, if not identical, to those used for rail transport.

The most likely way in which DOE would use barge transportation to make shipments to a repository would be to complete a leg of the trip that also involved two land legs. Even though many generator sites are adjacent to or near navigable waterways, shipping casks cannot be loaded directly onto barges in all cases. It would be necessary to use heavy-haul trucks or railcars to transport the casks from the generator site's cask loading facilities to a barge slip or dock. The casks would then either be rolled onto the barge using the land vehicle and a loading ramp and secured to the barge deck or hoisted from the land vehicle to the barge and secured. At the destination end of the barge leg of the trip, the cask would either be rolled off the barge using a ramp and a heavy-haul truck or hoisted from the barge deck onto a railcar or heavy-haul truck. The cask probably would then be transported from the destination port to Nevada by rail and not by heavy-haul truck. Thus, if casks were rolled off barges to heavy-haul trucks, they would need to be transferred to railcars. The maximum use of barge transportation would require transport through the Panama Canal for shipments from generator sites in the middle and eastern part of the United States. Such use could result in 70 percent fewer land travel kilometers than the mostly rail or mostly legal-weight truck scenario.

Analyses in the 1986 Environmental Assessment (DIRS 104731-DOE 1986, p. A-69) showed that the use of barge transportation would generally increase occupational exposure for normal shipment operations and could increase exposure of the public because of intermodal transfers. From the analyses, reactor-specific results suggest that under several circumstances the barge mode could reduce risk. The analyses concluded that the consequences of accidents from barges would be of the same magnitude as those for other modes.

Because, as discussed above, DOE could use barge transportation only in conjunction with land modes, DOE did not evaluate barge as an alternative major modal scenario as it did for the mostly rail and mostly legal-weight truck modal scenarios. Rather, for the 17 commercial generator sites not served by railroads but situated near or adjacent to navigable waterways, DOE evaluated and compared the potential use of barges and heavy-haul trucks to transport casks containing spent nuclear fuel from these sites to nearby railheads. The analysis assumed barges or heavy-haul trucks would be offloaded at the railheads and the casks would be transferred to railcars for shipment to Nevada.

DOE eliminated the large-scale barge scenario from further consideration in the EIS because it would be overly complex, requiring greater logistical complexity than either rail or legal-weight truck transportation; a much greater number of large rail casks than rail transport; much greater cost than either rail or legal-weight truck transportation; long transport distances potentially requiring the transit of the Panama Canal outside U.S. territorial waters; transport on intercoastal and coastal waterways of coastal states and on major rivers through and bordering states; extended transportation times; intermodal transfer operations at ports; and land transport from a western port to Yucca Mountain. If in the future DOE concluded that barge transportation was reasonable and proposed to make use of it, the Department would conduct additional National Environmental Policy Act evaluations to assess potential impacts of the greater use.

J.2.3 EFFECTS OF USING DEDICATED TRAINS OR GENERAL FREIGHT SERVICE

The Association of American Railroads recommends that only special (dedicated) trains move spent nuclear fuel and certain other forms of radioactive materials (DIRS 103718-DOT 1998, p. 2-6). In developing its recommendation, the Association concluded that the use of special trains would provide operational (for railroads and shippers) and safety advantages over shipments that used general freight service. Notwithstanding this recommendation, the U.S. Department of Transportation study (DIRS 103718-DOT 1998, all) compared dedicated and regular freight service using factors that measure impacts to overall public safety. The results of this study indicated that dedicated trains could provide advantages over regular trains for incident-free transportation but could be less advantageous for accident risks. However, available information does not indicate a clear advantage for the use of either dedicated trains or general freight service. Thus, DOE has not determined the commercial arrangements it would request from railroads for shipment of spent nuclear fuel and high-level radioactive waste. Table J-25 compares the dedicated and general freight modes. These comparisons are based on the findings of the U.S. Department of Transportation study and the Association of American Railroads.

J.2.4 IMPACTS OF THE SHIPMENT OF COMMERCIAL SPENT NUCLEAR FUEL BY BARGE AND HEAVY-HAUL TRUCK FROM 24 SITES NOT SERVED BY A RAILROAD

The mostly rail scenario includes 24 sites that do not have direct rail access. For those sites, heavy-haul trucks would be used to haul the spent nuclear fuel casks to the nearest railhead. As shown in Figure J-9 (a multipage figure), 17 of the 24 sites are on navigable waterways, so barge transport could be a feasible way to move spent nuclear fuel to the closest railhead with barge access. This section estimates the changes in impacts to the mostly rail scenario if barge transport replaced heavy-haul truck transport for these 17 sites.

J.2.4.1 Routes for Barges and Heavy-Haul Trucks

The distances from the 24 sites to railheads range from about 6 to 75 kilometers (4 to 47 miles). DOE used the HIGHWAY computer code to estimate routing for heavy-haul trucks (DIRS 104780-Johnson et al. 1993, all). The INTERLINE computer code (DIRS 104781-Johnson et al. 1993, all) was used to generate route-specific distances that would be traveled by barges. Table J-26 lists estimates for route lengths for barges and heavy-haul trucks. Table J-27 lists the number of shipments from each site.

Table J-25. Comparison of general freight and dedicated train service.

Attribute	General freight	Dedicated train
Overall accident rate for accidents that could damage shipping casks	Same as mainline railroad accident rates	Expected to be lower than general freight service because of operating restrictions and use of the most up-to-date railroad technology.
Grade crossing, trespasser, worker fatalities	Same as mainline railroad rates for fatalities	Uncertain. Greater number of trains could result in more fatalities in grade crossing accidents. Fewer stops in classification yards could reduce work related fatalities and trespasser fatalities.
Security	Security provided by escorts required by NRC[a] regulations	Security provided by escorts required by NRC regulations; fewer stops in classification yards than general freight service.
Incident-free dose to public	Low, but more stops in classification yards than dedicated trains. However, classification yards would tend to be remote from populated areas.	Lower than general freight service. Dedicated trains could be direct routed with fewer stops in classification yards for crew and equipment changes.
Radiological risks from accidents	Low, but greater than dedicated trains	Lower than general freight service because operating restrictions and equipment could contribute to lower accident rates and reduced likelihood of maximum severity accidents.
Occupational dose	Duration of travel influences dose to escorts	Shorter travel time would result in lower occupational dose to escorts.
Utilization of resources	Long cross-country transit times could result in least efficient use of expensive transportation cask resources; best use of railroad resources; least reliable delivery scheduling; most difficult to coordinate state notifications.	Direct through travel with on-time deliveries would result in most efficient use of cask resources; least efficient use of railroad resources. Railroad resource demands from other shippers could lead to schedule and throughput conflicts. Easiest to coordinate notification of state officials.

a. NRC = U.S. Nuclear Regulatory Commission.

J.2.4.2 Analysis of Incident-Free Impacts for Barge and Heavy-Haul Truck Transportation

J.2.4.2.1 *Radiological Impacts of Incident-Free Transportation*

This section compares radiological and nonradiological impacts to populations, workers, and maximally exposed individuals for the mostly rail case when casks from heavy-haul truck transport would be switched to barge for 17 of the 24 heavy haul truck sites. To make the comparison, the analysis retained any assumptions not affected by the mode change for the 17 sites. Thus:

- The seven sites that would ship by heavy-haul truck and do not have barge access would ship by heavy-haul truck in the barge case.
- The sites that would ship by legal-weight truck in the mostly rail case still ship by legal-weight truck for the barge analysis.
- For the rail segments of the routes that would use barge transport, separate INTERLINE runs determined the routes from the closest barge dock with rail access to each of the six end nodes in Nevada. While these routes are normally the same outside the origin state, no restrictions were imposed on INTERLINE requiring that the routes outside the origin state be the same.

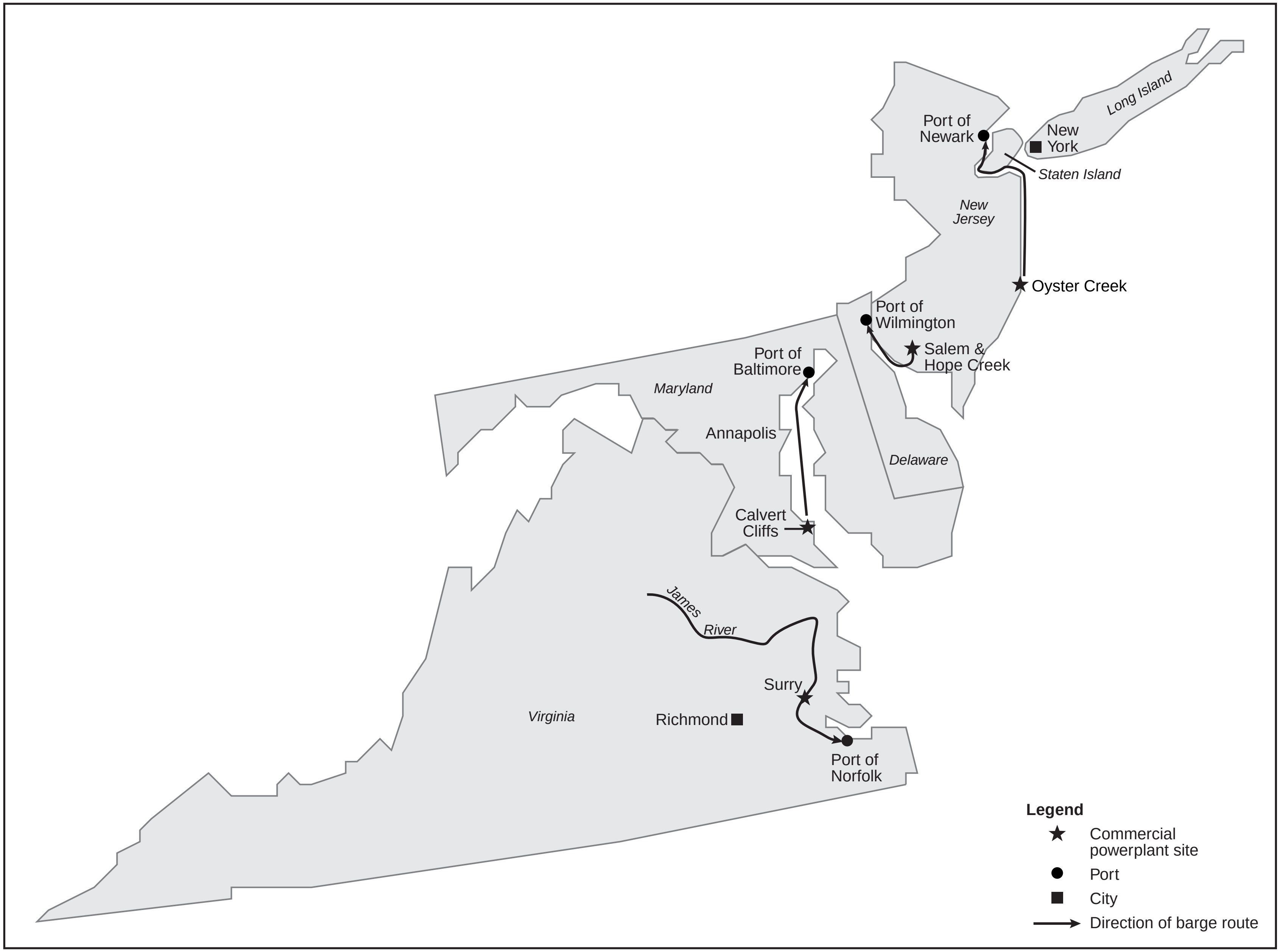

Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 1 of 4).

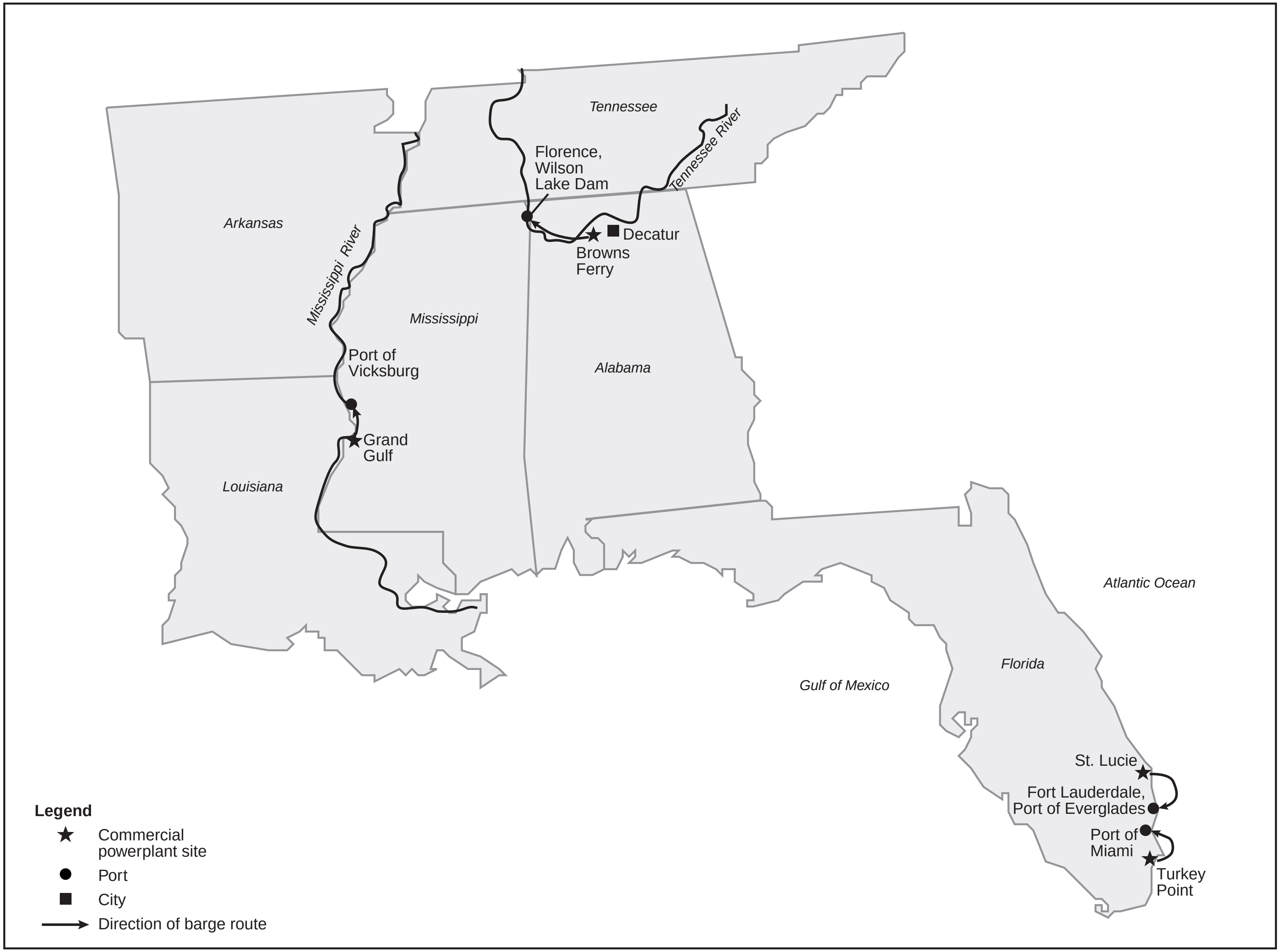

Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 2 of 4).

Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 3 of 4).

Figure J-9. Routes analyzed for barge transportation from sites to nearby railheads (page 4 of 4).

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers).[a,b]

Site (intermodal rail node)[c]	Rail transportation				Barge transportation			
	Total[d]	Rural	Suburban	Urban	Total[d]	Rural	Suburban	Urban
Browns Ferry NP[e]	3,279 - 3,656	2,985 - 3,306	260 - 300	34 - 49	57	51	5	0
Calvert Cliffs NP	4,028 - 4,404	3,270 - 3,592	610 - 650	148 - 162	99	98	2	0
Cooper NP	2,029 - 2,405	1,910 - 2,231	98 - 138	21 - 36	117	100	16	1
Diablo Canyon NP	582 - 1,453	375 - 1,006	112 - 311	94 - 136	143	143	0	0
Grand Gulf NP	3,298 - 3,665	2,859 - 3,333	270 - 373	28 - 67	51	51	0	0
Haddam Neck NP	4,339 - 4,716	3,316 - 3,637	842 - 882	182 - 197	99	89	10	0
Hope Creek NP	4,229 - 4,605	3,458 - 3,779	655 - 695	116 - 131	30	30	0	0
Indian Point NP	4,351 - 4,727	3,425 - 3,746	766 - 806	160 - 175	68	13	39	15
Kewaunee NP	2,864 - 3,241	2,506 - 2,827	291 - 331	68 - 82	177	171	1	5
Oyster Creek NP	4,337 - 4,714	3,420 - 3,741	765 - 806	152 - 167	130	77	36	17
Palisades NP	3,060 - 3,436	2,607 - 2,929	355 - 395	97 - 112	256	256	0	0
Pilgrim NP	4,393 - 4,769	3,338 - 3,659	858 - 899	196 - 211	74	41	33	0
Point Beach NP	2,864 - 3,241	2,506 - 2,827	291 - 331	68 - 82	169	163	1	5
Salem NP	4,229 - 4,605	3,458 - 3,779	655 - 695	116 - 131	34	34	0	0
St. Lucie NP	4,840 - 5,136	3,934 - 4,205	756 - 842	87 - 139	140	50	52	38
Surry NP	4,403 - 4,780	3,773 - 4,094	554 - 595	76 - 90	71	60	8	3
Turkey Point NP	4,882 - 5,178	3,937 - 4,208	765 - 851	117 - 169	54	53	0	1
Big Rock Point NP HH – 20.0 kilometers	3,258 - 3,595	2,766 - 3,059	399 - 431	93 - 105	--[f]	--	--	--
Callaway NP HH – 18.5 kilometers	2,491 - 2,868	2,352 - 2,674	119 - 159	20 - 35	--	--	--	--
Fort Calhoun NP HH – 6.0 kilometers	1,997 - 2,373	1,905 - 2,227	81 - 122	10 - 25	--	--	--	--
Ginna NP HH – 35.1 kilometers	3,532 - 3,869	2,792 - 3,086	604 - 636	136 - 147	--	--	--	--
Oconee NP HH – 17.5 kilometers	3,999 - 4,375	3,470 - 3,792	475 - 515	54 - 68	--	--	--	--
Peach Bottom NP HH – 58.9 kilometers	4,110 - 4,486	3,383 - 3,704	616 - 656	111 - 126	--	--	--	--
Yankee Rowe NP HH – 10.1 kilometers	3,998 - 4,335	3,083 - 3,376	752 - 784	164 - 175	--	--	--	--

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances estimated using INTERLINE computer program. Salem/Hope Creek treated as two sites.
c. Intermodal rail nodes selected for purpose of analysis. Source: (DIRS 104800-CRWMS M&O 1999, all).
d. Totals might differ from sums of rural, suburban, and urban distances due to method of calculation and rounding.
e. NP = nuclear plant.
f. -- = sites not located on a navigable waterway.

The analysis included radiological impacts of intermodal transfers at the interchange from heavy-haul trucks to railcars or barges to railcars. Workers would be exposed to radiation from casks during transfer operations. However, because the transfers would occur in terminals and berths remote from public access, public exposures would be small. Impacts of constructing intermodal transfer facilities were not included because intermodal transfers were assumed to take place at existing facilities.

The analysis assumed that heavy-haul trucks would travel at a lower speed than legal-weight trucks and that barge transport would be even slower. The assumed speed was 40 kilometers (25 miles) per hour and 8 kilometers (5 miles) per hour for heavy-haul truck and barge transport, respectively. These speeds were assumed to be independent of any population zone. Because travel distances to nearby railheads are short in relation to the distances traveled by rail, the expected impacts of heavy-haul truck and barge transportation would be much smaller than those of national rail shipments. The analysis of impacts for barge shipments assumed that the transport would employ commercial vessels operated by maritime

Table J-27. Barge shipments and ports.

Plant name	State	Number of shipments			Barge ports assumed for barge-to-rail intermodal transfer
		Proposed Action	Module 1	Module 2	
Browns Ferry 1	AL	122	247	248	Wilson Loading Dock
Browns Ferry 2	AL	0	0	1	Wilson Loading Dock
Browns Ferry 3	AL	51	120	121	Wilson Loading Dock
Diablo Canyon 1	CA	60	148	150	Port Huememe
Diablo Canyon 2	CA	61	160	162	Port Huememe
Haddam Neck	CT	40	40	42	Port of New Haven
St. Lucie 1	FL	12	13	16	Port Everglades
St. Lucie 2	FL	61	147	150	Port Everglades
Turkey Point 3	FL	52	85	87	Port of Miami
Turkey Point 4	FL	52	86	88	Port of Miami
Calvert Cliffs 1	MD	169	320	323	Port of Baltimore
Calvert Cliffs 2	MD	0	0	3	Port of Baltimore
Pilgrim	MA	24	18	19	Port of Boston
Palisades	MI	70	122	125	Port of Muskegon
Grand Gulf 1	MS	80	215	216	Port of Vicksburg
Cooper Station	NE	42	124	125	Port of Omaha
Hope Creek	NJ	67	105	106	Port of Wilmington
Oyster Creek 1	NJ	64	110	111	Port of Newark
Salem 1	NJ	59	101	103	Port of Wilmington
Salem 2	NJ	54	108	110	Port of Wilmington
Indian Point 1	NY	0	0	1	Port of Jersey City
Indian Point 2	NY	35	34	36	Port of Jersey City
Indian Point 3	NY	22	19	21	Port of Jersey City
Surry 1	VA	197	330	332	Port of Norfolk
Surry 2	VA	0	0	2	Port of Norfolk
Kewaunee	WI	64	110	111	Port of Milwaukee
Point Beach 1	WI	130	213	215	Port of Milwaukee
Point Beach 2	WI	0	0	2	Port of Milwaukee
Totals		***1,575***	***2,952***	***3,004***	

carriers on navigable waterways and that these shipments would follow direct routing from the sites to nearby railheads. For both modes, intermodal transfers would be necessary to transfer the casks to railcars.

The analysis estimated radiological impacts during transport for workers and the general population. For heavy-haul truck shipments, workers included vehicle drivers and escorts. For barge shipments, workers included five crew members on board during travel. In both the heavy-haul truck and barge cases, the workers would be far enough from the cask such that the major exposure would occur during periodic walkaround inspections. In both cases, consistent with the as-low-as-reasonably-achievable requirement guiding worker exposure, the analysis assumed that only one individual would perform these inspections. The general population for truck shipments included persons within 800 meters (about 2,600 feet) of the road (offlink), persons sharing the road (onlink), and persons at stops. The general population for barging included persons within a range of 200 to 1,000 meters (about 660 to 3,300 feet) of the route. Consistent with normal barge operations, the periodic walkaround inspections would occur while the barge was in motion and there was sufficient crew on board to eliminate the need for intermediate rest stops. Consistent with the RADTRAN 5 modeling, onlink exposures to members of the public during barging were assumed to be negligible. Incident-free unit risk factors were developed to calculate occupational and general population collective doses. Table J-28 lists the unit risk factors for heavy-haul truck and barge shipments. These factors reflect the effects of slower operating speeds for those vehicles in comparison to those for legal-weight trucks.

Table J-29 lists the incident-free impacts using the three shipment scenarios listed above. Impacts of intermodal transfers are included in the results. Occupational impacts would include the estimated radiological exposures of security escorts.

Table J-28. Risk factors for incident-free heavy-haul truck and barge transportation of spent nuclear fuel and high-level radioactive waste.

Mode	Exposure group	Incident-free risk factors (person-rem per kilometer)[a] Rural	Suburban	Urban
Heavy-haul truck	*Occupational*			
	Onlink[b]	5.54×10^{-6}	5.54×10^{-6}	5.54×10^{-6}
	Stops[b]	1.45×10^{-5}	1.45×10^{-5}	1.45×10^{-5}
	General population			
	Offlink[c]	6.24×10^{-8}	6.24×10^{-8}	6.24×10^{-8}
	Onlink[b]	1.01×10^{-4}	7.94×10^{-5}	2.85×10^{-4}
	Stops[b]	3.96×10^{-9}	3.96×10^{-9}	3.96×10^{-9}
	Overnight stop	2.62×10^{-3}		
Barge	*Occupational*[d]	2.11×10^{-6}	2.11×10^{-6}	2.11×10^{-6}
	General population			
	Offlink[c]	1.72×10^{-7}	1.72×10^{-7}	1.72×10^{-7}
	Onlink[b]	0.0	0.0	0.0
	Stops	0.0	0.0	0.0

a. The unit dose factors are developed from the equations in DIRS 155430-Neuhauser, Kanipe, and Weiner (2000, all) in the same way as the unit dose factors in Section J.1.3.
b. Onlink and stopped risk factors consider the exposure to the general population sharing the road and the crew transporting the cask. These factors must be multiplied by the number of shipments and the distance in kilometers in the zone for each segment of the route. The onlink vehicle density for rural transportation in Nevada was estimated using the annual average daily traffic on I-15 at the California-Nevada border (DIRS 103405-NDOT 1997, p. 4).
c. Offlink general population included persons from 30 to 800 meters (about 100 to 2,600 feet) of the road or railway and from 200 and 1,000 meters (about 650 and 3,300 feet) for barge. This risk factor must be multiplied by the number of shipments, distance in kilometers in the zone, and the population density (individuals per square kilometer) in the zone for each segment of the route.
d. Because heavy-haul vehicles cannot be in transit in Nevada for more than 12 hours, an overnight stop is modeled for routes that would require trips longer than 12 hours. This stop is not modeled for the short distances between reactor sites and railheads for indirect rail sites. When used, the factor is multiplied by the number of shipments.

Table J-29. Comparison of population doses and impacts from incident-free national transportation mostly rail heavy-haul truck scenario, mostly rail barge scenario, and mostly truck scenario.[a,b]

Category	Mostly rail (heavy-haul truck)[c]	Mostly rail (barge from 17 of 24 heavy-haul sites)[c]	Mostly truck
Involved worker			
Collective dose (person-rem)	4,300	4,400	14,100
Estimated LCFs[d]	1.7	1.7	5.6
Public			
Collective dose (person-rem)	1,500	1,400	5,000
Estimated LCFs	0.8	0.7	2.5
Maximally exposed individual			
Dose (rem)	0.29	0.29	3.2
Estimated emissions fatalities	0.0001[e]	0.0001[e]	0.0016[f]

a. Impacts are totals for all shipments over 24 years.
b. Includes impacts from intermodal transfer station (see Section 6.3.3.1).
c. Nevada impacts for the mostly rail routes have been averaged to show the effects of using barges at the origin.
d. LCF = latent cancer fatality.
e. Resident near a rail stop.
f. Person at a service station.

As indicated in Table J-29, the differences between the two mostly rail scenarios, heavy-haul truck and barge to nearby railheads, would be much smaller than the differences between the mostly rail scenarios and the mostly truck scenario. Considering only the mostly rail case options, heavy-haul and barge, the slower speed of the barge would tend to make barge exposures higher and the closest distance to resident population, 30 meters (100 feet) versus 200 meters (660 feet) for heavy-haul and barge, respectively, would tend to make barge exposures lower. Differences in the total exposed population or travel distances between the heavy-haul truck and barge routes could result in differences in the collective dose. Table J-29 indicates that the collective dose to the general public would be about the same as the barge case. Because workers would be well away from the cask during transport, the collective dose to workers would depend totally on the number of inspections performed during transit. Table J-29 indicates that these differences would be small. Based on this table, the barge scenario would have approximately the same impacts as the heavy-haul truck scenario that DOE used as a basis for the mostly rail results in Section J.1.3 and J.1.4.

J.2.4.2.2 *Nonradiological Impacts of Incident-Free Transportation (Vehicle Emissions)*

Table J-30 compares the estimated number of fatalities from vehicle emissions from shipments, assuming the use of heavy-haul trucks or barges to ship to nearby railheads.

Table J-30. Estimated population health impacts from vehicle emissions during incident-free national transportation for mostly rail heavy-haul truck and barge scenarios and the mostly legal-weight truck scenario.[a]

Category	Mostly rail (heavy-haul from 24 sites)	Mostly rail (heavy-haul truck from 7 sites and barge from 17)	Mostly truck
Estimated fatalities	0.63	0.62	0.93

a. Impacts are totals over 24 years, including impacts from an intermodal transfer station (see Chapter 6, Section 6.3.3.1).

J.2.4.3 Analysis of Impacts of Accidents for Barge and Heavy-Haul Truck Transportation

J.2.4.3.1 *Radiological Impacts of Accidents*

The analysis of risks from accidents during heavy-haul truck, rail, and legal-weight truck transport of spent nuclear fuel and high-level radioactive waste used the RADTRAN 5 computer code (DIRS 150898-Neuhauser and Kanipe 2000, all; DIRS 155430-Neuhauser, Kanipe, and Weiner 2000, all) in conjunction with an Access database and the analysis approach discussed in Section J.1.4.2. The analysis of risks due to barging used the same methodology with the exception of conditional probabilities. For barge shipments, the conditional accident probabilities and release fractions (Table J-31) for each cask response category were based on a review of other barge accident analyses.

The definitions of the accident severities listed in Table J-31 are based on the analyses reported in DIRS 152476-Sprung et al. (2000, pp. 7-75 to 7-76). DOE used the same accident severity category definitions as those used in the rail analysis described in Section J.1.4.2. If radioactive material was shipped by barge, both water and land contamination would be possible. DIRS 104784-Ostmeyer (1986, all) analyzed the potential importance of water pathway contamination for a spent nuclear fuel transportation accident risk using a “worst-case” water contamination scenario. The analysis showed that the impacts of the water contamination scenario would be about one-fiftieth of the impacts of a comparable accident on land. Therefore, the analysis assumed that deposition would occur over land, not water. DOE used population distributions developed from 1990 Census data to calculate route-specific collective doses. Table J-32 lists the total accident risk for mostly rail case heavy-haul truck scenario, the mostly rail case barge scenario, and the mostly truck scenario. Additional information is in Volume IV.

J.2.4.3.2 *Nonradiological Accident Risks*

As listed in Table J-32, the estimated total fatalities for the mostly rail heavy-haul truck scenario, the mostly rail barge scenario, and the mostly truck scenario would be 2.7, 2.7, and 4.5, respectively. There is essentially no difference between the two mostly rail scenarios. The only significant differences are between those scenarios, and the mostly truck case.

Table J-31. Release fractions and conditional probabilities for spent nuclear fuel transported by barge.

Severity category	Case	Conditional probability	Release fractions (pressurized-water reactor/boiling-water reactor)				
			Krypton	Cesium	Ruthenium	Particulates	Crud
1	21	0.994427	0.0	0.0	0.0	0.0	0.0
2	1, 4, 5, 7, 8	5.00×10^{-3}	$1.96 \times 10^{-1}/2.35 \times 10^{-2}$	$5.87 \times 10^{-9}/7.04 \times 10^{-10}$	$1.34 \times 10^{-7}/1.47 \times 10^{-8}$	$1.34 \times 10^{-7}/1.47 \times 10^{-8}$	$1.37 \times 10^{-3}/5.59 \times 10^{-4}$
3	20	5.00×10^{-6}	$8.39 \times 10^{-1}/8.39 \times 10^{-1}$	$1.68 \times 10^{-5}/1.68 \times 10^{-5}$	$2.52 \times 10^{-7}/2.52 \times 10^{-7}$	$2.52 \times 10^{-7}/2.52 \times 10^{-7}$	$9.44 \times 10^{-3}/9.44 \times 10^{-2}$
4	2, 3, 10	5.00×10^{-4}	$8.00 \times 10^{-1}/8.00 \times 10^{-1}$	$8.71 \times 10^{-6}/8.71 \times 10^{-6}$	$1.32 \times 10^{-5}/1.32 \times 10^{-5}$	$1.32 \times 10^{-5}/1.32 \times 10^{-5}$	$4.42 \times 10^{-3}/4.42 \times 10^{-2}$
5	6	0.0	$8.35 \times 10^{-1}/8.37 \times 10^{-1}$	$3.60 \times 10^{-5}/4.12 \times 10^{-5}$	$1.37 \times 10^{-5}/1.82 \times 10^{-5}$	$1.37 \times 10^{-5}/1.82 \times 10^{-5}$	$5.36 \times 10^{-3}/5.43 \times 10^{-3}$
6	9,11,12,13,14,15,16, 17,18,19	1.30×10^{-6}	$8.47 \times 10^{-1}/8.45 \times 10^{-1}$	$5.71 \times 10^{-5}/7.30 \times 10^{-5}$	$4.63 \times 10^{-5}/5.94 \times 10^{-5}$	$1.43 \times 10^{-5}/1.96 \times 10^{-5}$	$1.59 \times 10^{-2}/1.60 \times 10^{-2}$

Table J-32. Comparison of accident risks for the mostly rail heavy-haul truck and barge shipping scenarios.[a]

Category	Mostly rail (heavy-haul option–24 sites)	Mostly rail (barge option–17 of 24 heavy-haul sites)	Mostly truck
Population dose (person-rem)	0.89	1.5	0.5
Estimated LCFs[b]	0.00045	0.001	0.0002
Traffic fatalities[c]	2.7	2.7	4.5

a. Impacts are totals over 24 years.
b. LCF = latent cancer fatality.
c. Traffic fatality impacts for mostly rail scenarios are the average of the range of estimated traffic fatality impacts (2.3 to 3.1) for national transportation for the Proposed Action.

J.2.4.3.3 *Maximum Reasonably Foreseeable Accidents*

From a consequence standpoint, because DOE used the same accident severity bins for rail, heavy-haul truck, and barge transport, the consequences of a release would be the same if the accident occurred in a zone having the same population density. The population densities for barge and heavy-haul truck transport are similar to those for rail. Because the total shipping distance traveled by barge or heavy-haul truck would be a small fraction of the total distance traveled, the maximum reasonably foreseeable accident would be a rail accident. Only minor barge or heavy-haul truck transport accidents would meet the 1×10^{-7} criterion used to identify reasonably foreseeable accidents.

J.3 Nevada Transportation

With the exceptions of the possible construction of a branch rail line or upgrade of highways for use by heavy-haul trucks and the construction of an intermodal transfer station, the characteristics of the transportation of spent nuclear fuel and high-level radioactive waste in Nevada would be similar to those for transportation in other states across the nation. Unless the State of Nevada designated alternative or additional preferred routes as prescribed under regulations of the U.S. Department of Transportation (49 CFR 397.103), Interstate System Highways (I-15) would be the preferred routes used by legal-weight trucks carrying spent nuclear fuel and high-level radioactive waste. Unless alternative or non-Interstate System routes have been designated by states, Interstate System highways would also be the preferred routes used by legal-weight trucks in other states during transit to Nevada.

In Nevada as in other states, rail shipments would, for the most part, be transported on mainline tracks of major railroads. Operations over a branch rail line in Nevada would be similar to those on a mainline railroad, except the frequency of train travel would be much lower. Shipments in Nevada that used heavy-haul trucks would use Nevada highways in much the same way that other overdimensional, overweight trucks use the highways along with other commercial vehicle traffic.

Some State- and county-specific assumptions were used to analyze human health and safety impacts in Nevada. A major difference would be that much of the travel in the State would be in rural areas where population densities are much lower than those of many other states. Another difference would be for travel in an urban area in the state. The most populous urban area in Nevada is the Las Vegas metropolitan area, which is also a major resort area with a high percentage of nonresidents. The analysis also addressed the channeling of shipments from the commercial and DOE sites into the transportation arteries in the southern part of the State. Finally, the analysis addressed the commuter and commercial travel that would occur on highways in the southern part of the State as a consequence of the construction, operation and monitoring, and closure of the proposed repository.

This section presents information specific to Nevada that DOE used to estimate impacts for transportation activities that would take place in the State. It includes results for cumulative impacts that would occur in Nevada for transportation associated with Inventory Modules 1 and 2.

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J.3.1 TRANSPORTATION MODES, ROUTES, AND NUMBER OF SHIPMENTS

J.3.1.1 Routes in Nevada for Legal-Weight Trucks

The analysis of impacts that would occur in Nevada used the characteristics of highways in Nevada that would be used for shipments of spent nuclear fuel and high-level radioactive waste by legal-weight trucks. Specifically, the base case for the analysis used routing for the Las Vegas Northern and Western Beltway to transport spent nuclear fuel and high-level radioactive waste. The distance and population density by county was obtained from Geographical Information System data for the State of Nevada using 1990 Census data. The population density data was escalated to 2035.

Figure J-10 shows the routes in Nevada that legal-weight trucks would use unless the State designated alternative or additional preferred routes. The figure shows estimates for the number of legal-weight truck shipments that would travel on each route segment for the mostly legal-weight truck and mostly rail transportation scenarios. The inset on Figure J-10 shows the Las Vegas Beltway and the routes DOE anticipates legal-weight trucks traveling to the repository would use.

J.3.1.2 Highway and Rail Routes in Nevada for Transporting Rail Casks

The rail and heavy-haul truck implementing alternatives for transportation in Nevada include five possible rail corridors and five possible routes for heavy-haul trucks; the corridors and routes for these implementing alternatives are shown in Figures J-11 and J-12. These figures also show the estimated number of rail shipments that would enter the State on mainline railroads. These numbers indicate shipments that would arrive from the direction of the bordering state for each of the implementing alternatives for the mostly rail transportation scenario.

Table J-33 lists the total length and cumulative distance in rural, suburban, and urban population zones and the population density in each population zone in the State of Nevada used to analyze impacts of the implementing alternatives. Table J-34 lists the cumulative distance in rural, suburban, and urban population zones and the population density in each population zone for existing commercial rail lines in Nevada. DOE based the estimated population that would live along each branch rail line on population densities in census blocks along the candidate rail corridors in Nevada. The populations are based on 1990 Census data escalated to 2035. For this analysis, the ending rail nodes in Nevada for commercial rail lines would be origins for the rail and heavy-haul truck alternatives listed in Table J-33. Table J-35 lists the total population that lives within 800 meters (0.5 mile) of rail lines in Nevada.

Nevada Heavy-Haul Truck Scenario

Tables J-36 through J-40 summarize the road upgrades for each of the five possible routes for heavy-haul trucks that DOE estimates would be needed before routine use of a route to ship casks containing spent nuclear fuel and high-level radioactive waste.

Nevada Rail Corridors

Under the mostly rail scenario, DOE could construct and operate a branch rail line in Nevada. Based on the studies listed below, DOE has narrowed its consideration for a new branch rail line to five potential rail corridors—Carlin, Caliente, Caliente-Chalk Mountain, Jean, and Valley Modified. DOE identified the five rail corridors through a process of screening potential rail alignments that it had studied in past years. Several studies evaluated rail transportation.

- The *Feasibility Study for Transportation Facilities to Nevada Test Site* study (DIRS 104777-Holmes & Narver 1962, all) determined the technical and economic feasibility of constructing and operating a railroad from Las Vegas to Mercury.

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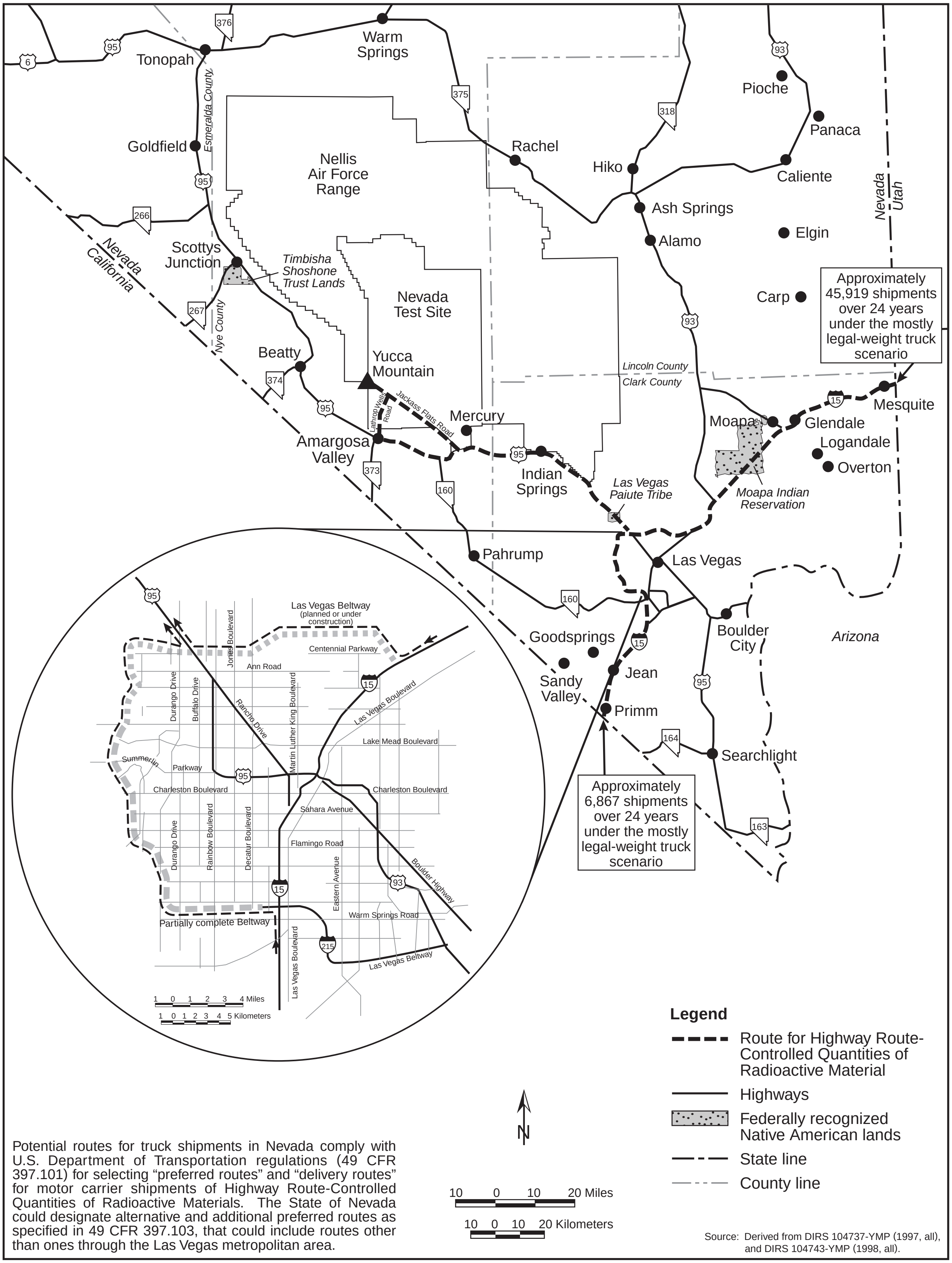


Figure J-10. Potential Nevada routes for legal-weight trucks and estimated number of shipments.

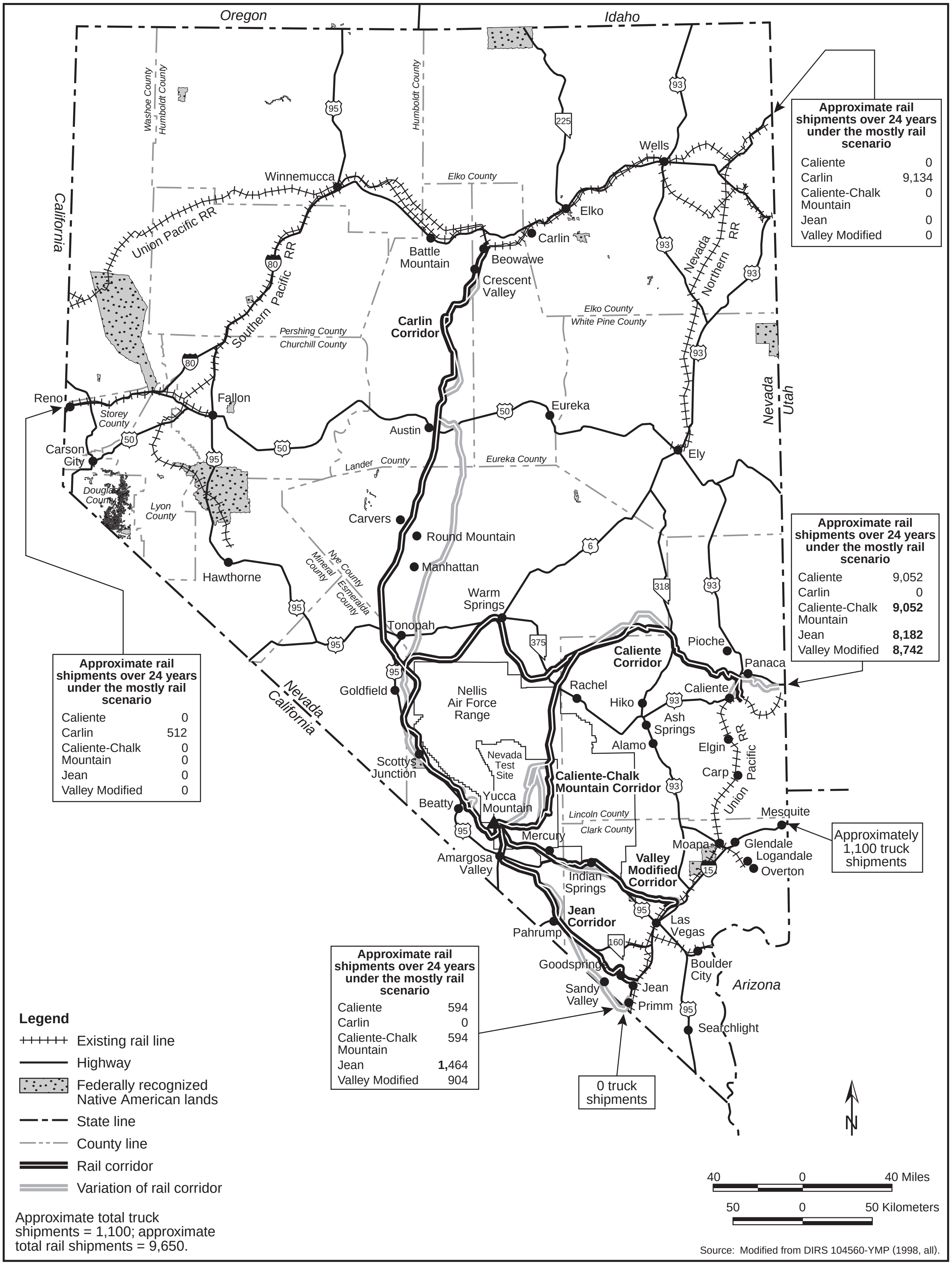


Figure J-11. Potential Nevada rail routes to Yucca Mountain and estimated number of shipments.

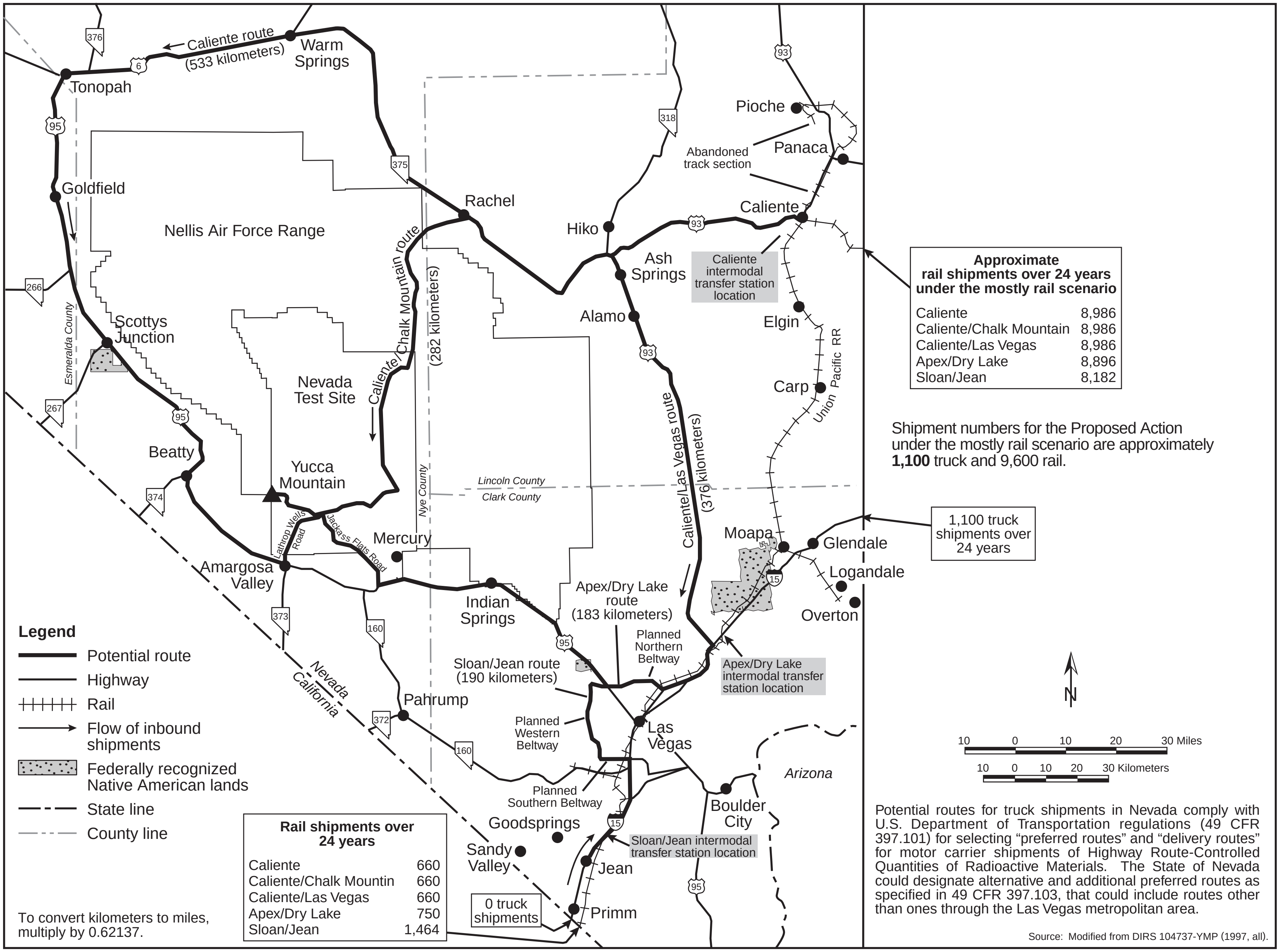


Figure J-12. Potential Nevada routes for heavy-haul trucks and estimated number of shipments.

Table J-33. Routing characteristics in Nevada for legal-weight truck, rail and heavy-haul truck implementing alternatives.

Route	County	Distance (kilometers)[a]				Population density (persons per square kilometer)		
		Urban	Suburban	Rural	Total	Urban	Suburban	Rural
Legal-weight truck route in Nevada using the Las Vegas Beltway								
Northern route	Clark	0.0	19.9	187.5	207.4	0.0	577	10.6
Northern route	Nye	0.0	0.0	64.7	64.7	0.0	0.0	0.0
Southern route	Clark	0.0	41.9	126.9	168.8	0.0	577	3.5
Southern route	Nye	0.0	0.0	64.7	64.7	0.0	0.0	0.0
Rail alternatives								
Caliente-Chalk Mountain	Lincoln	0.0	0.0	158.0	158.0	0.0	0.0	0.0
Caliente-Chalk Mountain	Nye	0.0	0.0	188.0	188.0	0.0	0.0	0.0
Caliente	Esmeralda	0.0	0.0	4.0	4.0	0.0	0.0	0.3
Caliente	Lincoln	0.0	0.0	148.5	148.5	0.0	0.0	0.0
Caliente	Nye	0.0	0.0	360.8	360.8	0.0	0.0	0.1
Carlin	Eureka	0.0	0.0	29.8	29.8	0.0	0.0	0.1
Carlin	Lander	0.0	0.0	158.7	158.7	0.0	0.0	0.0
Carlin	Esmeralda	0.0	0.0	41.0	41.0	0.0	0.0	0.4
Carlin	Nye	0.0	0.0	291.5	291.5	0.0	0.0	0.6
Jean	Clark	0.0	0.0	82.4	82.4	0.0	0.0	0.8
Jean	Nye	0.0	0.0	98.2	98.2	0.0	0.0	0.2
Apex	Clark	0.0	0.0	99.5	99.5	0.0	0.0	0.1
Apex	Nye	0.0	0.0	59.2	59.2	0.0	0.0	0.0
Heavy-haul alternatives								
Apex/Dry Lake	Clark	0.0	19.9	104.0	123.9	0.0	577	2.9
Apex/Dry Lake	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.001
Caliente	Esmeralda	0.0	0.0	71.6	71.6	0.0	0.0	2.0
Caliente	Lincoln	0.0	0.0	148.5	148.5	0.0	0.0	0.8
Caliente	Nye	0.0	4.7	308.5	313.2	0.0	261	0.7
Caliente/Las Vegas	Clark	0.0	19.9	147.3	167.2	0.0	577	2.1
Caliente/Las Vegas	Lincoln	0.0	0.0	149.7	149.7	0.0	0.0	0.8
Caliente/Las Vegas	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.001
Caliente/Chalk Mountain	Lincoln	0.0	0.0	146.9	146.9	0.0	0.0	0.9
Caliente/Chalk Mountain	Nye	0.0	0.0	135.3	135.3	0.0	0.0	0.0
Jean/Sloan	Clark	0.0	41.9	88.6	130.5	0.0	577	5.3
Jean/Sloan	Nye	0.0	0.0	59.4	59.4	0.0	0.0	0.0006

a. To convert kilometers to miles, multiply by 0.62137.

- The *Preliminary Rail Access Study* (DIRS 104792-YMP 1990, all) identified 13 and evaluated 10 rail corridor alignment options. This study recommended the Carlin, Caliente, and Jean Corridors for detailed evaluation.

- *The Nevada Railroad System: Physical, Operational, and Accident Characteristics* (DIRS 104735-YMP 1991, all) described the operational and physical characteristics of the current Nevada railroad system.

- The *High Speed Surface Transportation Between Las Vegas and the Nevada Test Site (NTS)* report (DIRS 104786-Cook 1994, all) explored the rationale for a potential high-speed rail corridor between Las Vegas and the Nevada Test Site to accommodate personnel.

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 1* (DIRS 104795-CRWMS M&O 1995, all), reevaluated 13 previously identified rail routes and evaluated a new route called the Valley Modified route. This study recommended four rail corridors for detailed evaluation—Caliente, Carlin, Jean, and Valley Modified.

Table J-34. Routing characteristics in Nevada for existing commercial rail lines.

			Distance (kilometers)[a]				Population density (persons per square kilometer)		
End node	Route	County	Urban	Suburban	Rural	Total	Urban	Suburban	Rural
Beowawe	NV existing rail via Utah	Eureka	0.0	0.0	31.5	31.5	0.0	0.0	0.1
Beowawe	NV existing rail via Utah	Elko	0.0	11.3	218.1	229.3	0.0	463.4	2.0
Beowawe	NV existing rail via Reno	Humboldt	0.0	6.4	103.8	110.2	0.0	431.4	5.5
Beowawe	NV existing rail via Reno	Pershing	0.0	3.2	117.8	121.0	0.0	377.0	2.6
Beowawe	NV existing rail via Reno	Lander	0.0	3.2	41.0	44.3	0.0	577.3	3.5
Beowawe	NV existing rail via Reno	Eureka	0.0	0.0	22.7	22.7	0.0	0.0	0.1
Beowawe	NV existing rail via Reno	Washoe	3.2	23.3	26.8	53.4	1,953.2	517.6	14.9
Beowawe	NV existing rail via Reno	Churchill	0.0	0.0	66.8	66.8	0.0	0.0	0.0
Beowawe	NV existing rail via Reno	Storey	0.0	2.4	18.0	20.4	0.0	199.9	8.7
Beowawe	NV existing rail via Reno	Lyon	0.0	3.2	14.7	18.0	0.0	586.9	12.9
Jean	NV existing rail Jean from south	Clark	0.0	0.0	41.7	41.7	0.0	0.0	1.0
Jean	NV existing rail Jean from north	Clark	3.2	17.7	110.0	130.9	1,879.6	750.6	0.8
Jean	NV existing rail Jean from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Apex	NV existing rail Apex from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Apex	NV existing rail Apex from north	Clark	0.0	0.0	50.8	50.8	0.0	0.0	2.0
Apex	NV existing rail Apex from south	Clark	3.2	17.7	100.9	121.8	1,879.6	750.6	1.4
Caliente	NV existing routing to Caliente from north	Lincoln	0.0	0.0	64.7	64.7	0.0	0.0	0.8
Caliente	NV existing routing to Caliente from south	Clark	3.2	17.7	151.7	172.6	1,879.6	750.6	1.6
Caliente	NV existing routing to Caliente from south	Lincoln	0.0	1.6	103.1	104.7	0.0	294.3	0.9
Eccles	NV existing routing to Eccles from north	Lincoln	0.0	0.0	56.3	56.3	0.0	0.0	0.0
Eccles	NV existing routing to Eccles from south	Clark	3.2	17.7	151.7	172.6	1,879.6	750.6	1.6
Eccles	NV existing routing to Eccles from south	Lincoln	0.0	1.6	111.4	113.1	0.0	294.3	1.3
Dry Lake	NV existing routing to Dry Lake from north	Lincoln	0.0	1.6	167.8	169.4	0.0	294.3	0.8
Dry Lake	NV existing routing to Dry Lake from north	Clark	0.0	0.0	50.8	50.8	0.0	0.0	2.0
Dry Lake	NV existing routing to Dry Lake from south	Clark	3.2	17.7	100.9	121.8	1,879.6	750.6	1.4

a. To convert kilometers to miles, multiply by 0.62157.

Table J-35. Populations in Nevada within 800 meters (0.5 mile) of routes.[a,b]

Transportation scenario	Population 2035 projections
Legal-weight truck routes[a]	190,000/300,000
Rail routes Nevada border to branch rail line[b]	
Caliente (from the North – UT)	110
Caliente (from the South – CA)	115,000
Beowawe (from the east – UT)	21,000
Beowawe (from the west – CA)	98,000
Eccles (from the North – UT)	3
Eccles (from the south – CA)	115,000
Jean (from the North – UT)	114,000
Jean (from the South – CA)	250
Dry Lake (from the North – UT)	1,900
Dry Lake (from the South – CA)	113,000
Branch rail lines	
Caliente	140
Carlin	1,280
Caliente-Chalk Mountain	31
Jean	520
Valley Modified	75
Heavy-haul routes	
Caliente	11,000
Caliente/Chalk Mountain	740
Caliente/Las Vegas	187,000
Sloan/Jean	390,000
Apex/Dry Lake	186,000

a. The estimated populations represent using the route from the north and from the south, respectively.
b. The analysis assumed there would be an average of 800,000 visitors per day to Las Vegas.

Table J-36. Potential road upgrades for Caliente route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to U.S. 6	Remove existing pavement, increase road base and overlay to remove frost restrictions, truck lanes where grade is greater than 4 degrees (minimum distance of 460 meters per lane), turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
U.S. 6 to U.S. 95	Same as State Route 375 to U.S. 6.
U.S. 95 to Lathrop Wells Road	Remove existing pavement on frost restricted portion, increase base and overlay to remove frost restrictions, turnout lanes every 8 kilometers (distance of 305 meters per lane), construct bypass around intersection at Beatty, bridge upgrade near Beatty.
Lathrop Wells Road to Yucca Mountain site	Asphalt overlay on existing roads.

a. Source: DIRS 154448-CRWMS M&O (1998, all).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-37. Potential road upgrades for Caliente/Chalk Mountain route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road
State Route 375 to Rachel	Remove existing pavement, increase road base and overlay to remove frost restrictions, turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
Rachel to Nellis Air Force Range[d]	Pave existing gravel road.
Nellis Air Force Range Roads	Rebuild existing road.
Nevada Test Site Roads	Asphalt overlay on existing roads.

a. Source: DIRS 155436-CRWMS M&O (1997, all).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.
d. Also known as the Nevada Test and Training Range.

Table J-38. Potential road upgrades for Caliente/Las Vegas route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to Interstate 15	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes, asphalt overlay on U.S. 95.
U.S. 95 to Mercury	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-39. Potential road upgrades for Apex/Dry Lake route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Rebuild frontage road to U.S. 93. Rebuild U.S. 93/Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).

Table J-40. Potential road upgrades for Sloan/Jean route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Overlay and widen existing road to Interstate 15 interchange, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: DIRS 154448-CRWMS M&O (1998, all).

- The *Nevada Potential Repository Preliminary Transportation Strategy*, *Study 2* (DIRS 101214-CRWMS M&O 1996, all), further refined the analyses of potential rail corridor alignments presented in Study 1.

Public comments submitted to DOE during hearings on the scope of this environmental impact statement resulted in addition of a fifth corridor—Caliente-Chalk Mountain.

DOE has identified 0.4-kilometer (0.25-mile)-wide corridors along each route within which it would need to obtain a right-of-way to construct a rail line and an associated access road. A corridor defines the boundaries of the route by identifying an established “zone” for the location of the railroad. For this analysis, DOE identified a single alignment for each of the corridors. These single alignments are representative of the range of alignments that DOE has considered for the corridors from engineering design and construction viewpoints. The following paragraphs describe the alignments that have been identified for the corridors. Before siting a branch rail line, DOE would conduct engineering studies in each corridor to determine a specific alignment for the roadbed, track, and right-of-way for a branch rail line.

Caliente Corridor Implementing Alternative. The Caliente Corridor originates at an existing siding to the Union Pacific mainline railroad near Caliente, Nevada. The Caliente and Carlin Corridors converge near the northwest boundary of the Nellis Air Force Range (also known as the Nevada Test and Training Range). Past this point, they are identical. The Caliente Corridor is 513 kilometers (320 miles) long from the Union Pacific line connection to the Yucca Mountain site. Table J-41 lists possible alignment variations for this corridor.

Carlin Corridor Implementing Alternative. The Carlin Corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada. The corridor is about 520 kilometers (331 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-42 lists possible variations in the alignment of this corridor.

Caliente-Chalk Mountain Corridor Implementing Alternative. The Caliente-Chalk Mountain Corridor is identical to the Caliente Corridor until it approaches the northern boundary of the Nellis Air Force Range (also known as the Nevada Test and Training Range). At this point the Caliente-Chalk Mountain Corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site. The corridor is 345 kilometers (214 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-43 lists possible alignment variations for this corridor.

Jean Corridor Implementing Alternative. The Jean Corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada. The corridor is 181 kilometers (112 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-44 lists possible variations for this corridor.

Valley Modified Corridor Implementing Alternative. The Valley Modified Corridor originates at an existing rail siding off the Union Pacific mainline railroad northeast of Las Vegas. The corridor is about 159 kilometers (98 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-45 lists the possible variations in alignment for this corridor.

Land Use Conflicts Along Potential Rail Corridors in Nevada

Figures J-13 through J-20 show potential land-use conflicts along candidate rail corridors for construction of a branch rail line in Nevada.

Table J-41. Possible variations of the Caliente Corridor.[a]

Variation	Description[b]
Eccles Option	Included in corridor description. Crosses private land and BLM lands. No ROWs crossed.
Caliente Option[c]	Connects with Union Pacific line at existing siding in Town of Caliente. Crosses approximately twice the amount of private lands than the primary alignment. Crosses 2 ROWs – 1 telephone and 1 road (U.S. 93).
Crestline Option[c]	Connects with Union Pacific line near east end of existing siding at Crestline. Crosses approximately twice the private land as the corridor. Crosses 2 ROWs – 1 telephone and 1 road.
White River Alternate[c]	Avoids potential conflict of the corridor with Weepah Spring Wilderness Study Area. Would cross approximately 0.012 square kilometer (3 acres) of private land.
Garden Valley Alternate[c]	Puts more distance between corridor and private lands in Garden Valley and Coal Valley. Crosses 2 road ROWs and 2 pipelone ROWs. Crosses approximately same amount of private land as corridor.
Mud Lake Alternate[c]	Travels farther from west edge of Mud Lake, which has known important archaeological sites. Mud Lake contains 4 possible route variations that are located on BLM lands.
Goldfield Alternate[c]	Avoids crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.75 square kilometer of private lands.
Bonnie Claire Alternate[c]	Avoids crossing Nellis Air Force Range boundary near Scottys Junction, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.43 square kilometer of private property. Crosses a BLM utility corridor, 3 road ROWs, 2 telephone ROWs, and 4 power ROWs. Crosses Timbisha Shoshone trust lands parcel.
Oasis Valley Alternate[c]	Enables flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected a route through this area, further studies would ensure small environmental impacts.
Beatty Wash Alternate[c]	Provides alternate corridor through Beatty Wash that is longer, but requires less severe earthwork than the corridor.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way.
c. Common with Carlin Corridor.

Minority Populations Along Potential Transportation Routes in Nevada

Census Bureau information available to DOE and considered in this EIS includes geographical identification of census blocks containing minority populations within the environmental justice definition used by DOE (that is, a minority population is one in which the percent of the population of an area's racial or ethnic minority is 44.8 percentage points or more of the total population).

There is no corresponding census block information for low-income populations. To provide the information on minority census blocks to decisionmakers and the public, DOE has prepared a set of maps (Figures J-21 through J-30) showing the location of minority census blocks near potential transportation corridors. The maps depict 6-kilometer bands on each side of each corridor.

Darkly shaded areas represent minority blocks in or near the 6-kilometer bands. Lightly shaded areas represent the balance of land within the 6-kilometer bands. Dotted areas of intermediate shading represent Native American lands. All lands shown on maps and not represented as minority block or Native American is land that does not have a minority population within the definition used in this EIS (see Chapter 3, Section 3.1.13.1) to consider environmental justice concerns.

Table J-42. Possible variations of the Carlin Corridor.[a]

Variation	Description[b]
Crescent Valley Alternate	Diverges from the corridor near Cortez Mining Operation where it would cross a proposed pipeline ROW that would supply water to the Dean Ranch; travels through nonagricultural lands adjacent to alkali flats but would affect larger area of private land. Crosses 2 existing roads, one of which has an established ROW.
Wood Spring Canyon Alternate	Diverges from the corridor and use continuous 2-percent grade to descend from Dry Canyon Summit in Toiyabe range; is shorter than the corridor segment but would have steeper grade. Continues on BLM land.
Rye Patch Alternate	Travels through Rye Patch Canyon, which has springs, riparian areas, and game habitats; diverts from the corridor, maintaining distance of 420 meters[c] from Rye Patch Spring and at least 360 meters from riparian areas throughout Rye Patch Canyon, except at crossing of riparian area near south end of canyon; avoids game habitat (sage grouse strutting area). Passes through a BLM utility corridor, one road and one road ROW (U.S. 50).
Steiner Creek Alternate	Diverges from the corridor at north end of Rye Patch Canyon. Avoids crossing private lands, two known hawk-nesting areas, and important game habitat (sage grouse strutting area) in the corridor. Passes close to Steiner Creek WSA.
Smoky Valley Option	Travels through less populated valley than Monitor Valley Option. Crosses more ROWs than Monitor Valley Option. Passes through all BLM land until route enters NTS. Passes through a Desert Land Entry area.
Monitor Valley Option	Travels through less populated Monitor Valley (in comparison to Big Smoky Valley). Crosses the Monitor, Ralston, and Potts grazing allotments. Also passes through 2 areas with application to Desert Land Entry Program. Passes 2 road ROWs, 1 telephone, 1 pipeline, and 3 powerline ROWs.
Mud Lake Alternate[d]	Travels farther from west edge of Mud Lake, which has known important archaeological sites. Mud Lake contains 4 possible route variations that are located on BLM lands.
Goldfield Alternate[d]	Avoids crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.75 square kilometer[e] of private lands.
Bonnie Claire Alternate[d]	Avoids crossing Nellis Air Force Range boundary near Scottys Junction, avoiding potential land-use conflicts with Air Force. Crosses mostly BLM lands but also crosses approximately 0.43 square kilometer of private property. Crosses a BLM utility corridor, 3 road ROWs, 2 telephone ROWs, and 4 power ROWs. Crosses Timbisha Shoshone trust lands parcel.
Oasis Valley Alternate[d]	Enables flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected a route through this area, further studies would ensure small environmental impacts.
Beatty Wash Alternate[d]	Provides alternate corridor through Beatty Wash that is longer, but requires less severe earthwork than the corridor.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; NTS = Nevada Test Site; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert meters to feet, multiply by 3.2808.
d. Common with Caliente corridor.
e. To convert square kilometers to acres, multiply by 247.1.

Although the populations of most census blocks are small, the size of many blocks is large. The depiction of minority blocks does not show the location of any residences within blocks. Census bureau data did not include residential locations. No inference should be drawn from these maps as to the location of residences within depicted areas.

Table J-43. Possible variations of the Caliente-Chalk Mountain Corridor.

Variation	Description
Caliente Option	Same as Table J-41. Connects with Union Pacific Line at existing siding in Town of Caliente.
Eccles Option	Same as Table J-41.
Orange Blossom Option	Crosses Nevada Test Site land. Bypasses roads and facilities.
Crestline Option	Same as Table J-41. Connects with Union Pacific line near east end of existing siding at Caliente.
White River Alternate	Same as Table J-41. Avoids potential conflict with Weepah Springs Wilderness Study Area.
Garden Valley Alternate	Same as Table J-41. Puts more distance between rail corridor and private lands in Garden Valley and Coal Valley.
Mercury Highway Option	To provide flexibility in choosing path through Nevada Test Site, travels north through center of Nevada Test Site. Requires slightly less land [approximately 0.2 square kilometers (50 acres)] than corridor. Crosses Mercury Highway.
Topopah Option	To provide flexibility in choosing path through Nevada Test Site, travels north along western boundary of Nevada Test Site.
Mine Mountain Alternate	Provides flexibility in minimizing impacts to local archaeological sites.
Area 4 Alternate	Provides flexibility in choosing path through Nevada Test Site. Crosses Mercury Highway. Requires slightly less land.

a. Source: DIRS 155628-CRWMS M&O (1997, all).

J.3.1.3 Sensitivity of Analysis Results to Routing Assumptions

In addition to analyzing the impacts of using highway routes that would meet U.S. Department of Transportation requirements for transporting spent nuclear fuel, DOE evaluated how the estimated impacts would differ if legal-weight trucks used other routes in Nevada. Six other routes identified in a 1989 study by the Nevada Department of Transportation (DIRS 103072-Ardila-Coulson 1989, pp. 36 and 45) were selected for this analysis. The Nevada Department of Transportation study described the routes as follows:

Route A. Minimum distance and minimum accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on Nevada 318, south on U.S. 93, south on I-15, west on Craig Road, north on U.S. 95

Route B. Minimum population density and minimum truck accident rate.
Both of these two routes use the U.S. 6 truck bypass in Ely.

Alternative route possibilities were identified between I-15 at Baker, California and I-40 at Needles, California to Mercury. These alternative routes depend upon the use of U.S. 95 in California, California 127 and the Nipton Road.

Route C. From Baker with California 127.
North on California 127, north on Nevada 373, south on U.S. 95

Route D. From Baker without California 127.
North on I-15, west on Nevada 160, south on U.S. 95

Route E. From Needles with U.S. 95, California 127, and the Nipton Road.
North on U.S. 95, west on Nevada 164, west on I-15, north on California 127, north on Nevada 373, south on U.S. 95

Route F. From Needles without California 127 and the Nipton Road.
West on I-40, east on I-15, west on Nevada 160, south on U.S. 95

Table J-43. Possible variations of the Caliente-Chalk Mountain Corridor.

Variation	Description
Caliente Option	Same as Table J-41. Connects with Union Pacific Line at existing siding in Town of Caliente.
Eccles Option	Same as Table J-41.
Orange Blossom Option	Crosses Nevada Test Site land. Bypasses roads and facilities.
Crestline Option	Same as Table J-41. Connects with Union Pacific line near east end of existing siding at Caliente.
White River Alternate	Same as Table J-41. Avoids potential conflict with Weepah Springs Wilderness Study Area.
Garden Valley Alternate	Same as Table J-41. Puts more distance between rail corridor and private lands in Garden Valley and Coal Valley.
Mercury Highway Option	To provide flexibility in choosing path through Nevada Test Site, travels north through center of Nevada Test Site. Requires slightly less land [approximately 0.2 square kilometers (50 acres)] than corridor. Crosses Mercury Highway.
Topopah Option	To provide flexibility in choosing path through Nevada Test Site, travels north along western boundary of Nevada Test Site.
Mine Mountain Alternate	Provides flexibility in minimizing impacts to local archaeological sites.
Area 4 Alternate	Provides flexibility in choosing path through Nevada Test Site. Crosses Mercury Highway. Requires slightly less land.

a. Source: DIRS 155628-CRWMS M&O (1997, all).

J.3.1.3 Sensitivity of Analysis Results to Routing Assumptions

In addition to analyzing the impacts of using highway routes that would meet U.S. Department of Transportation requirements for transporting spent nuclear fuel, DOE evaluated how the estimated impacts would differ if legal-weight trucks used other routes in Nevada. Six other routes identified in a 1989 study by the Nevada Department of Transportation (DIRS 103072-Ardila-Coulson 1989, pp. 36 and 45) were selected for this analysis. The Nevada Department of Transportation study described the routes as follows:

Route A. Minimum distance and minimum accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on Nevada 318, south on U.S. 93, south on I-15, west on Craig Road, north on U.S. 95

Route B. Minimum population density and minimum truck accident rate.
Both of these two routes use the U.S. 6 truck bypass in Ely.

Alternative route possibilities were identified between I-15 at Baker, California and I-40 at Needles, California to Mercury. These alternative routes depend upon the use of U.S. 95 in California, California 127 and the Nipton Road.

Route C. From Baker with California 127.
North on California 127, north on Nevada 373, south on U.S. 95

Route D. From Baker without California 127.
North on I-15, west on Nevada 160, south on U.S. 95

Route E. From Needles with U.S. 95, California 127, and the Nipton Road.
North on U.S. 95, west on Nevada 164, west on I-15, north on California 127, north on Nevada 373, south on U.S. 95

Route F. From Needles without California 127 and the Nipton Road.
West on I-40, east on I-15, west on Nevada 160, south on U.S. 95

Table J-44. Possible variations of the Jean Corridor.[a]

Variation	Description[b]
North Pahrump Valley Alternate	Minimizes impacts to approximately 4 kilometers[c] of private land on northeast side of Pahrump. Abuts Toiyabe National Forest and a BLM corridor. Travels within a BLM utility corridor. Crosses approximately twice as much BLM lands as corridor and 0.0999 square kilometer[d] of private land compared to 3.5 square kilometers.
Wilson Pass Option	Crosses 2 pipeline ROWs, 3 road/highway ROWs, 2 powerline ROWs. Enter BLM utility corridor for approximately 46 kilometers. Passes within 1.6 kilometers of Toiyabe National Forest and close to 3 mines. Also passes through BLM Class II visual resource lands.
Stateline Pass Option	Provides option to crossing Spring Mountains at Wilson Pass; diverges from corridor in Pahrump Valley; parallels Nevada-California border, traveling along southwestern edge of Spring Mountains and crossing border twice. Bypasses private land crossed by primary alignment. Origination of option would conflict with the proposed Ivanpah Valley Airport. Crosses 2 pipeline ROWs, 2 road ROWs, 1 powerline, 1 telephone ROW, 1 withdrawal area (unexplained), a BLM utility corridor, and 1 community pit. Passes close to Stateline WSA. Crosses Black Butte and Roach Lake grazing allotments.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert kilometers to miles, multiply by 0.62137.
d. To convert square kilometers to acres, multiply by 247.1.

Table J-45. Possible variations of the Valley Modified Corridor.[a]

Variation	Description[b]
Indian Hills Alternate	Avoids entrance to Nellis Air Force Range north of Town of Indian Springs by traveling south of town. U.S. Fish and Wildlife Service land. Crosses 1 road, 2 telephone, and 2 powerline ROWs. Passes almost entirely within BLM utility corridor. Passes through a land withdrawal area.
Sheep Mountain Alternate	Increases distance from private land in Las Vegas and proposed 30-square-kilometer[c] BLM land exchange with city. Crosses small parcels (approximately 0.18 square kilometer) of private land. Crosses 3 powerline ROWs. Passes through Nellis Small Arms Range, Nellis WSAs A, B, and C, the Desert National Wildlife Range, and the Quail Spring WSA.
Valley Connection	Locates transfer operations at Union Pacific Valley Yard rather than Dike siding. Overflights of Dike siding from Nellis Air Force Base could conflict with switching operations. Crosses slightly more private land.

a. Source: DIRS 131242-CRWMS M&O (1997, all).
b. Abbreviations: BLM = Bureau of Land Management; ROW = right-of-way; WSA = Wilderness Study Area.
c. To convert square kilometers to acres, multiply by 247.1.

Table J-46 identifies the sensitivity cases evaluated based on the Nevada Department of Transportation routes. Tables J-47 and J-48 list the range of impacts in Nevada of using these different routes for the mostly legal-weight truck analysis scenario. The tables compare the impacts estimated for the highways identified in the Nevada study to those estimated for shipments that would follow routes allowed by current U.S. Department of Transportation regulations for Highway Route-Controlled Quantities of Radioactive Materials. Because the State of Nevada has not designated alternative or additional preferred routes for use by these shipments, as permitted under U.S. Department of Transportation regulations (49 CFR 397.103), DOE has assumed that shipments of spent nuclear fuel and high-level radioactive waste would enter Nevada on I-15 from either the northeast or southwest. The analysis assumed that shipments traveling on I-15 from the northeast would use the northern Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site. Shipments from the southwest on I-15 would use the southern and western Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site.

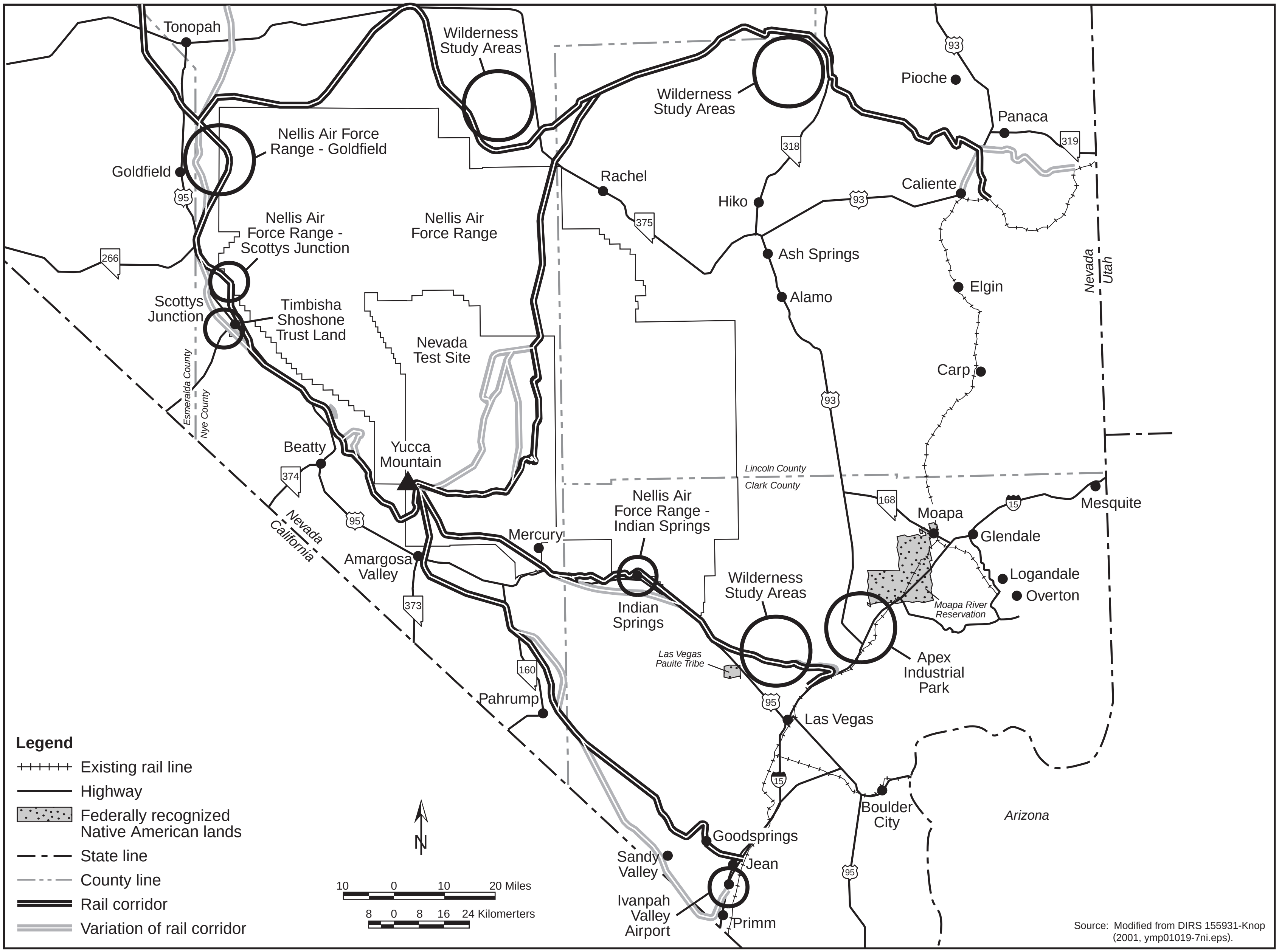


Figure J-13. Land-use conflicts along Nevada rail corridors, overview.

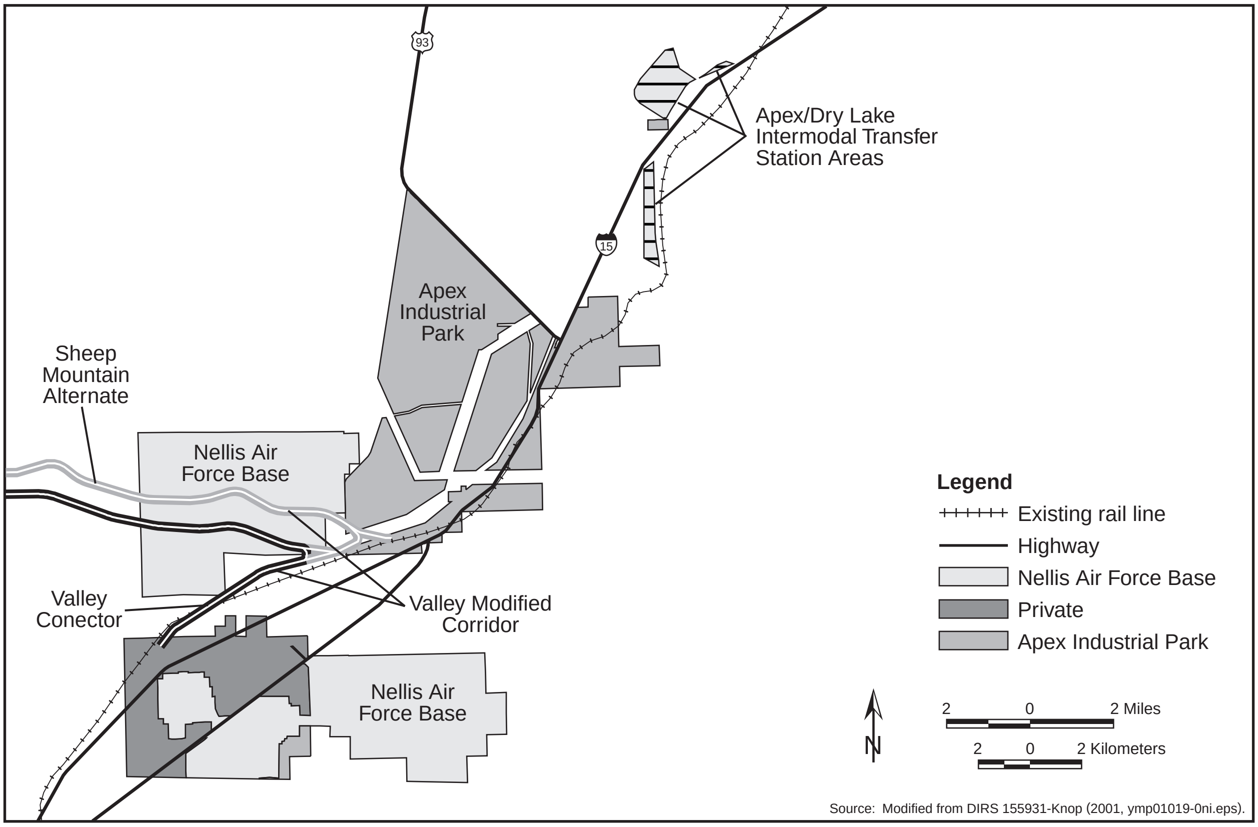


Figure J-14. Land-use conflicts along Nevada rail corridors, Apex Industrial Park.

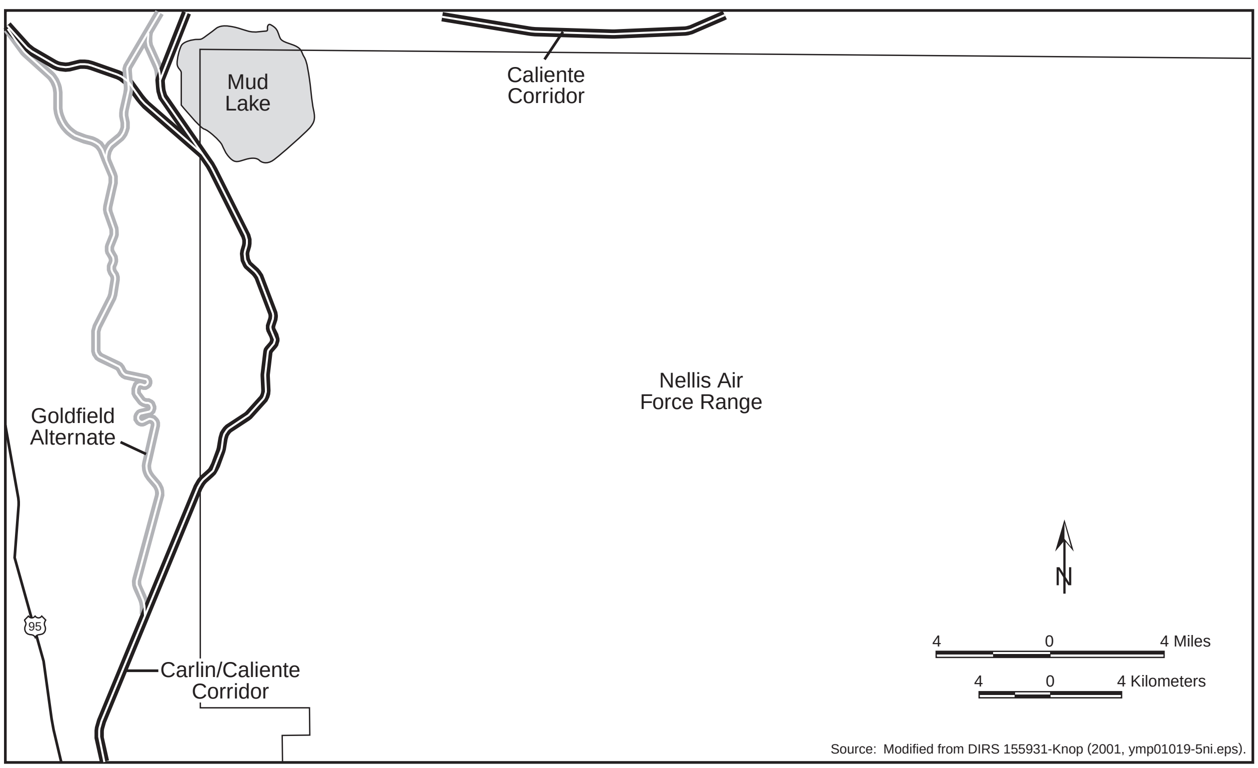
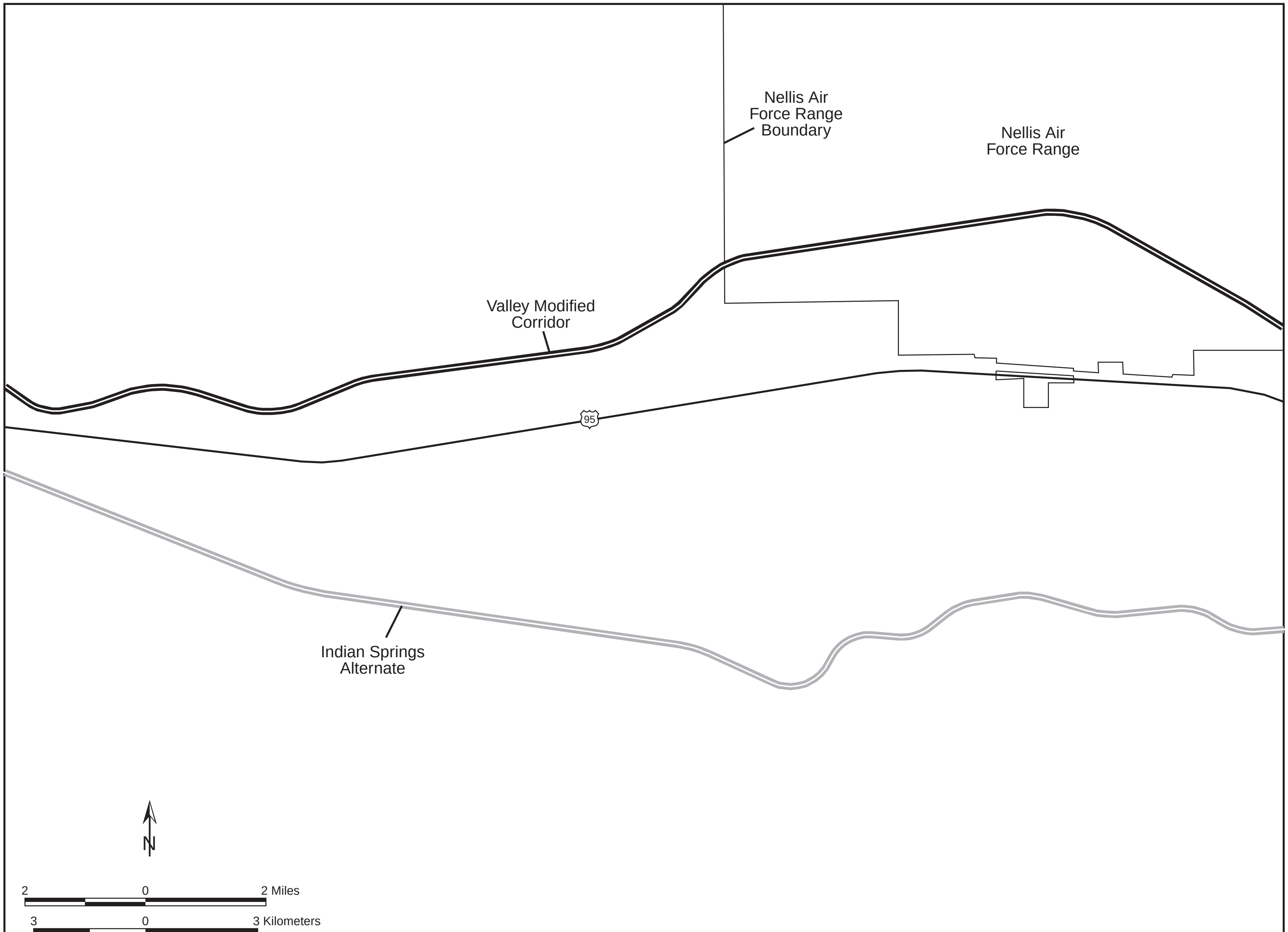


Figure J-15. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Goldfield area.



Source: Modified from DIRS 155931-Knop (2001, ymp01019-3ni.eps).

Figure J-16. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Indian Springs area.

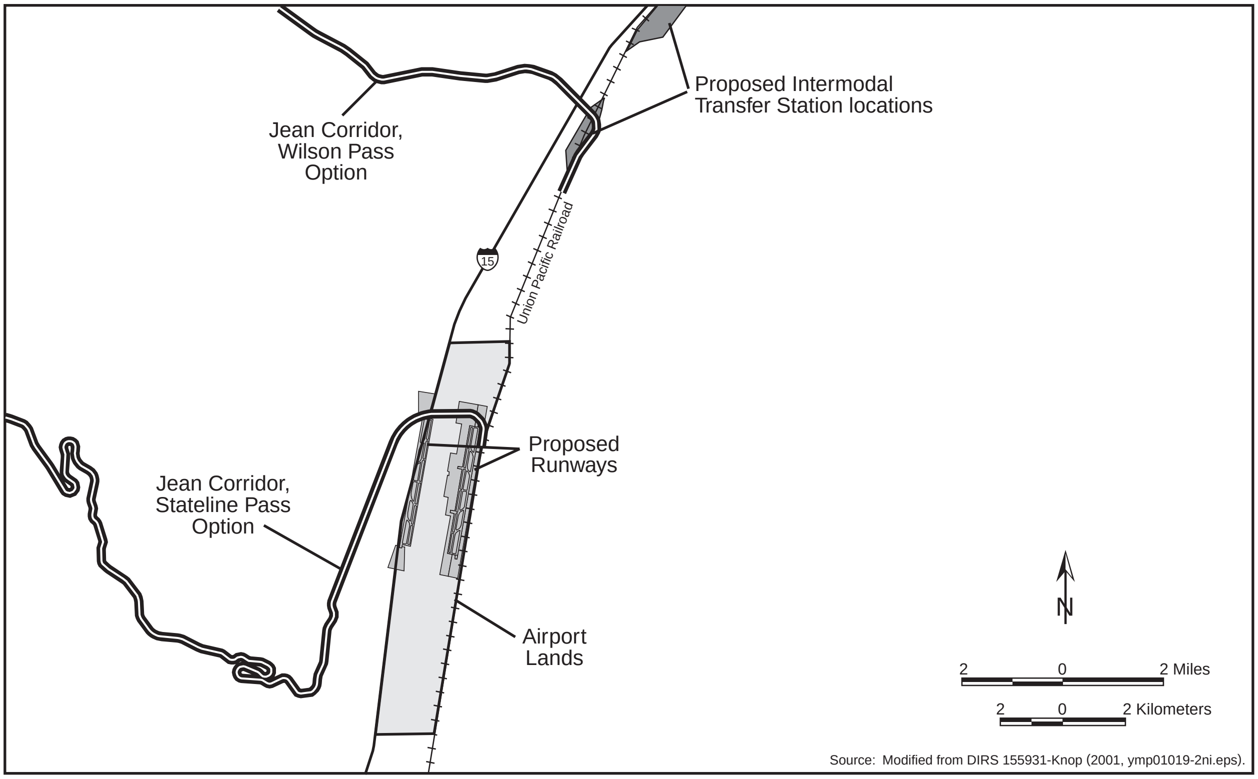


Figure J-17. Land-use conflicts along Nevada rail corridors, Ivanpah Valley Airport Public Lands Transfer Act.

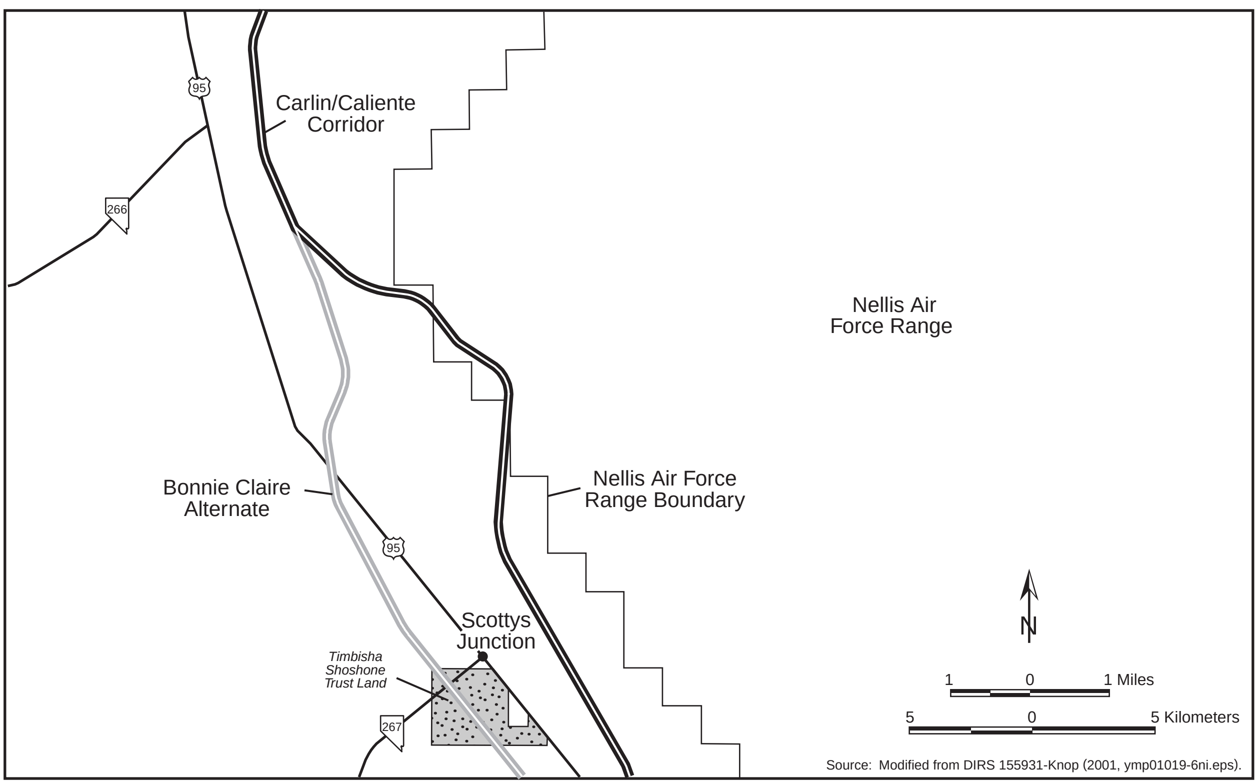


Figure J-18. Land-use conflicts along Nevada rail corridors, Nellis Air Force Range, Scottys Junction area.

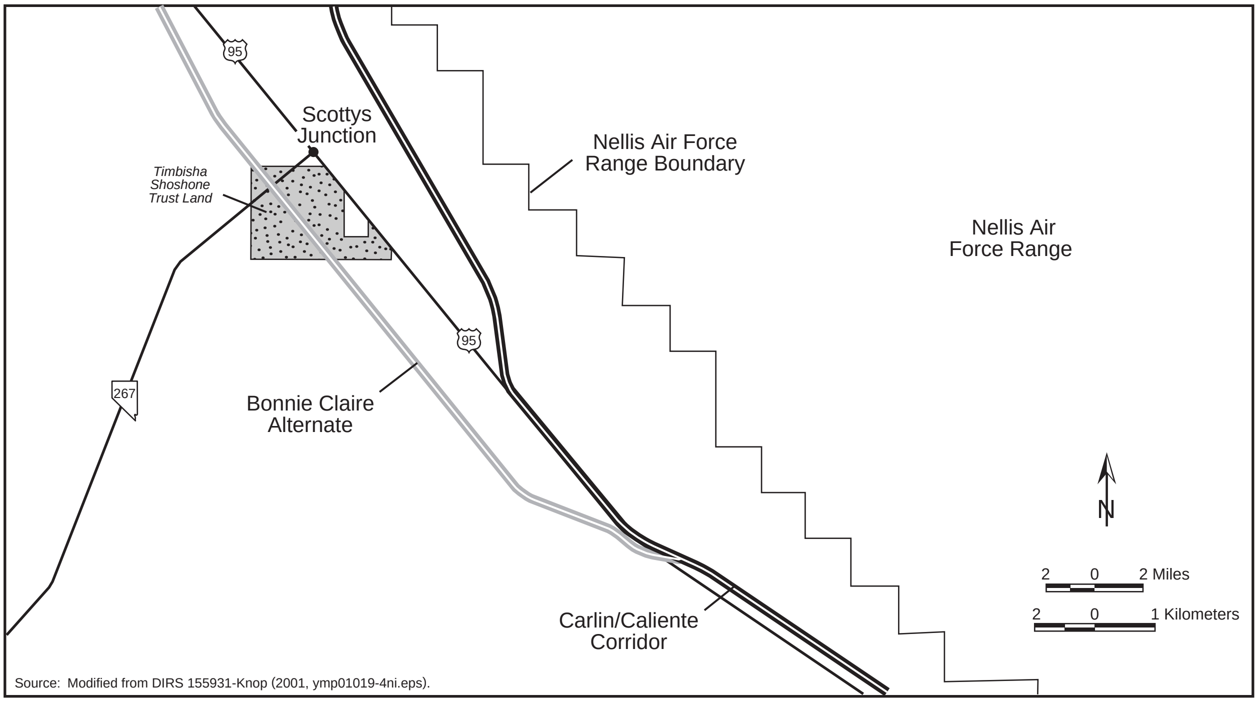


Figure J-19. Land-use conflicts along Nevada rail corridors, Timbisha Shoshone Trust Lands.

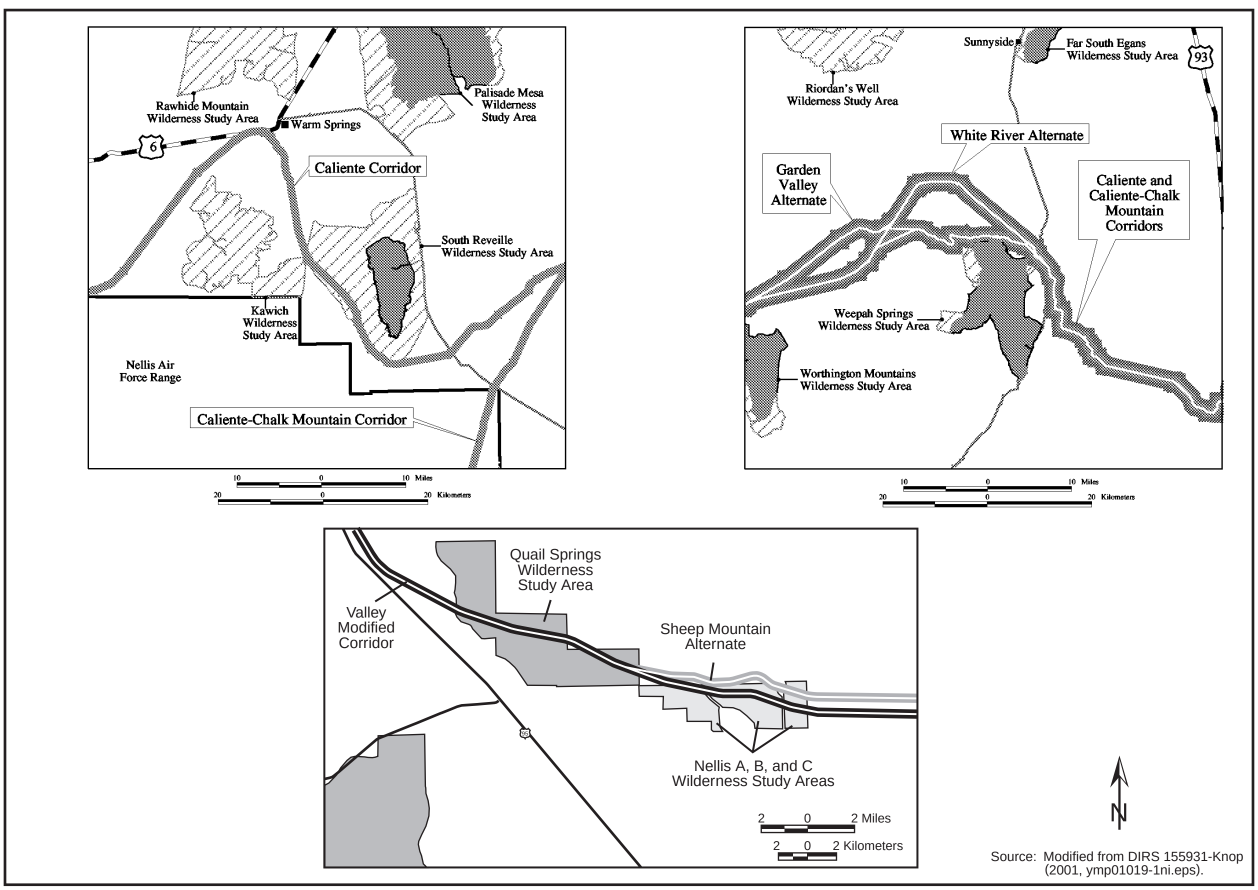


Figure J-20. Land-use conflicts along Nevada rail corridors, Wilderness Study Areas.

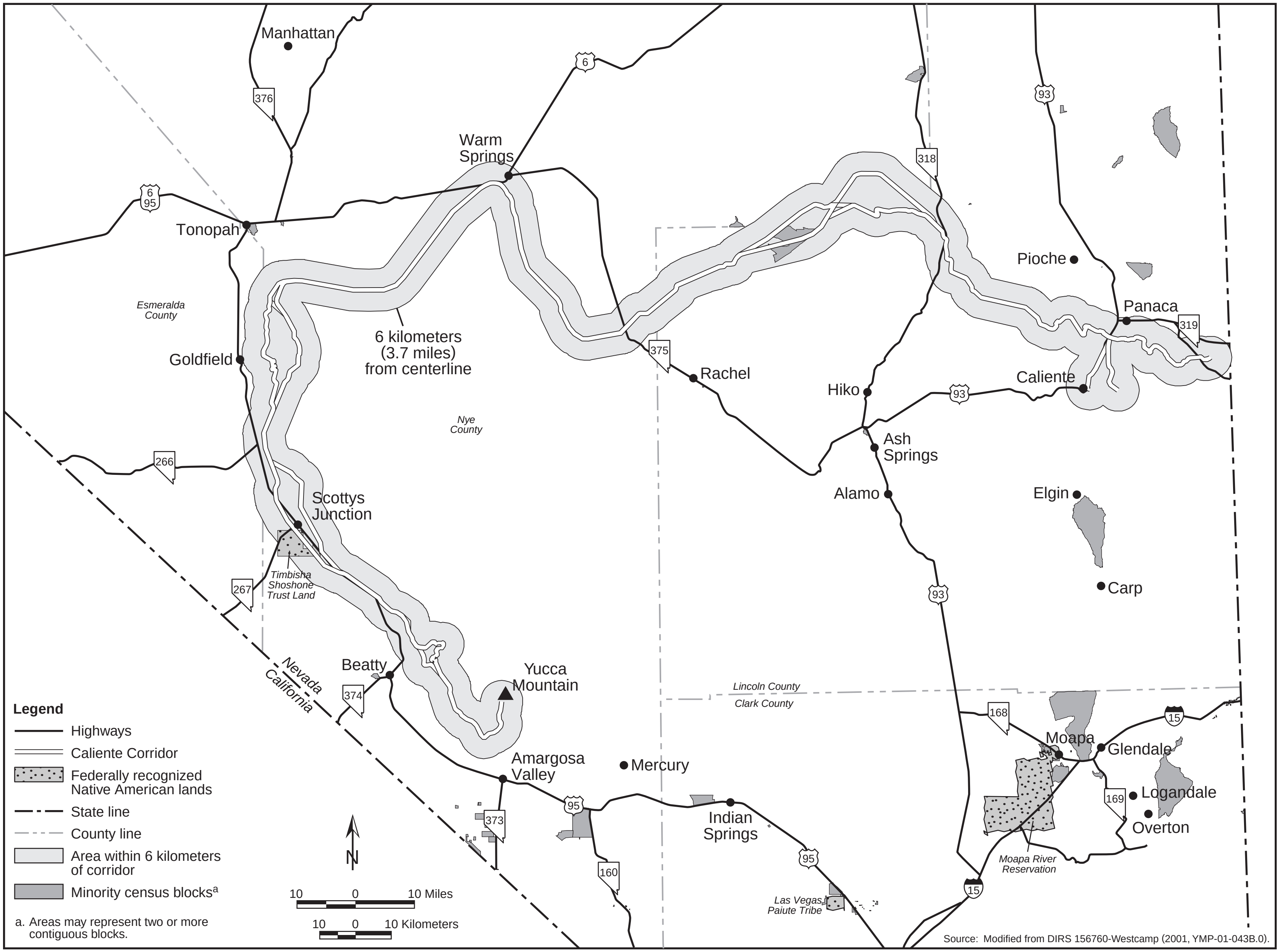


Figure J-21. Nevada minority census blocks in relation to the Caliente Corridor.

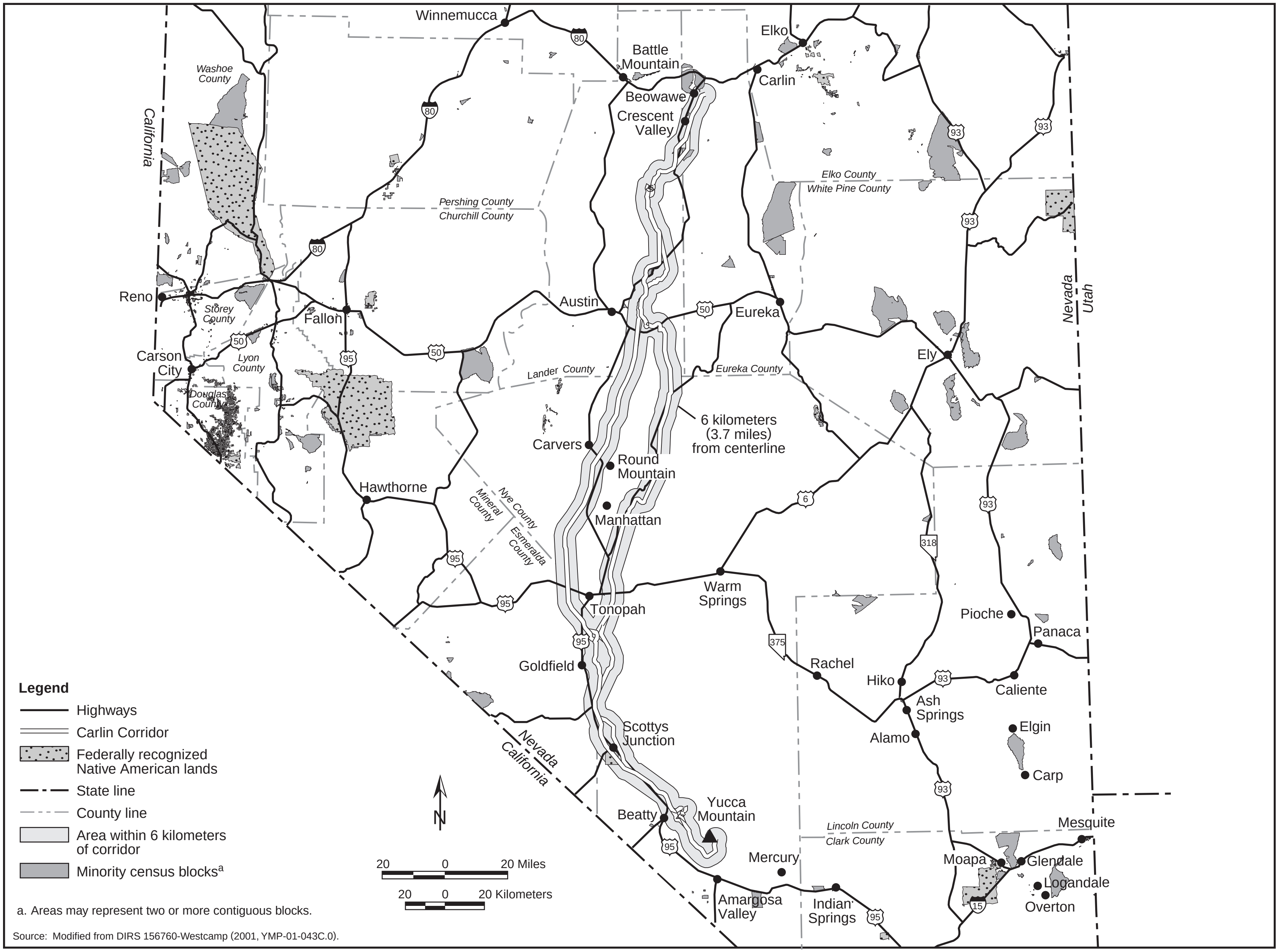


Figure J-22. Nevada minority census blocks in relation to the Carlin Corridor.

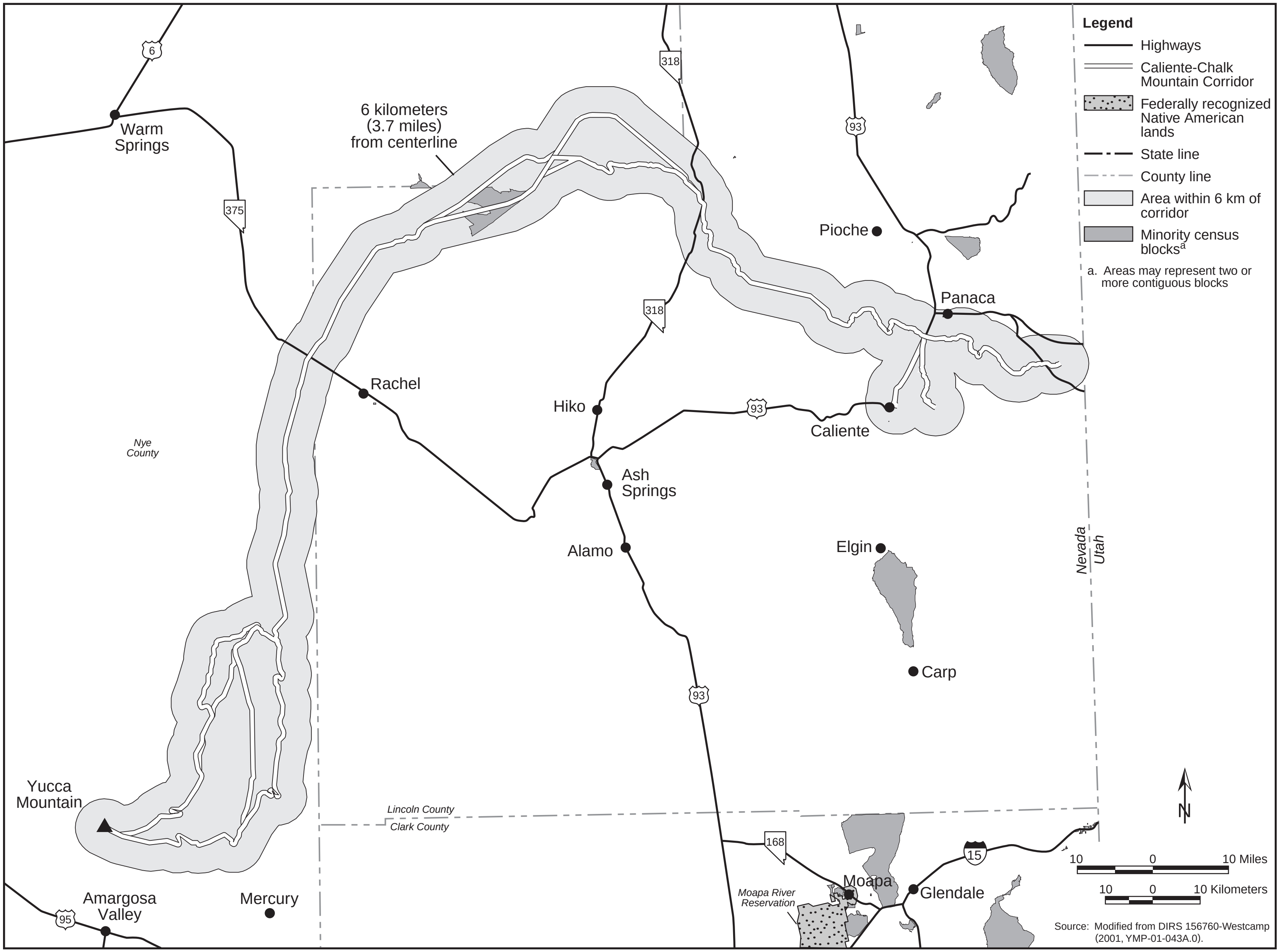


Figure J-23. Nevada minority census blocks in relation to the Caliente-Chalk Mountain Corridor.

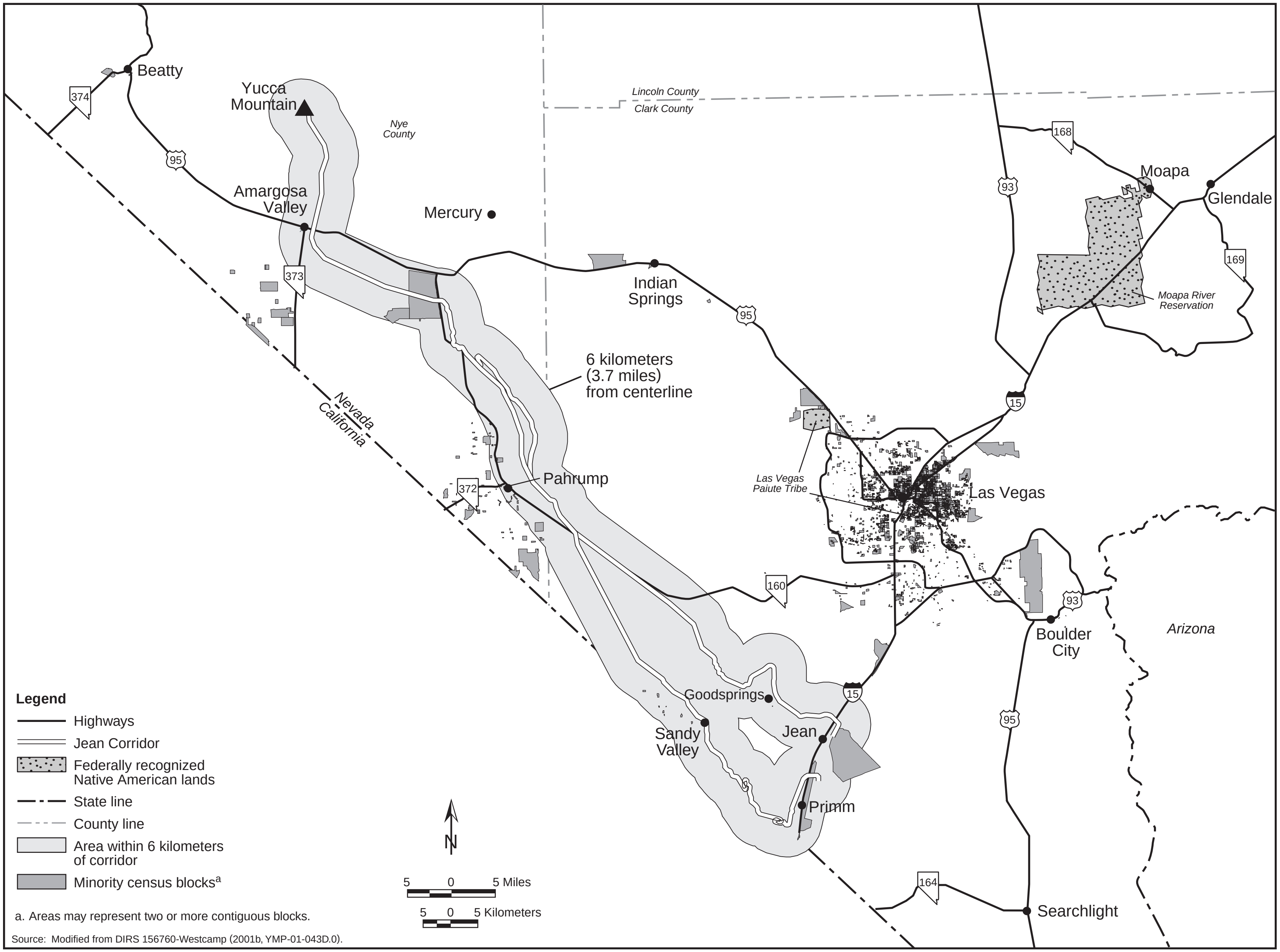


Figure J-24. Nevada minority census blocks in relation to the Jean Corridor.

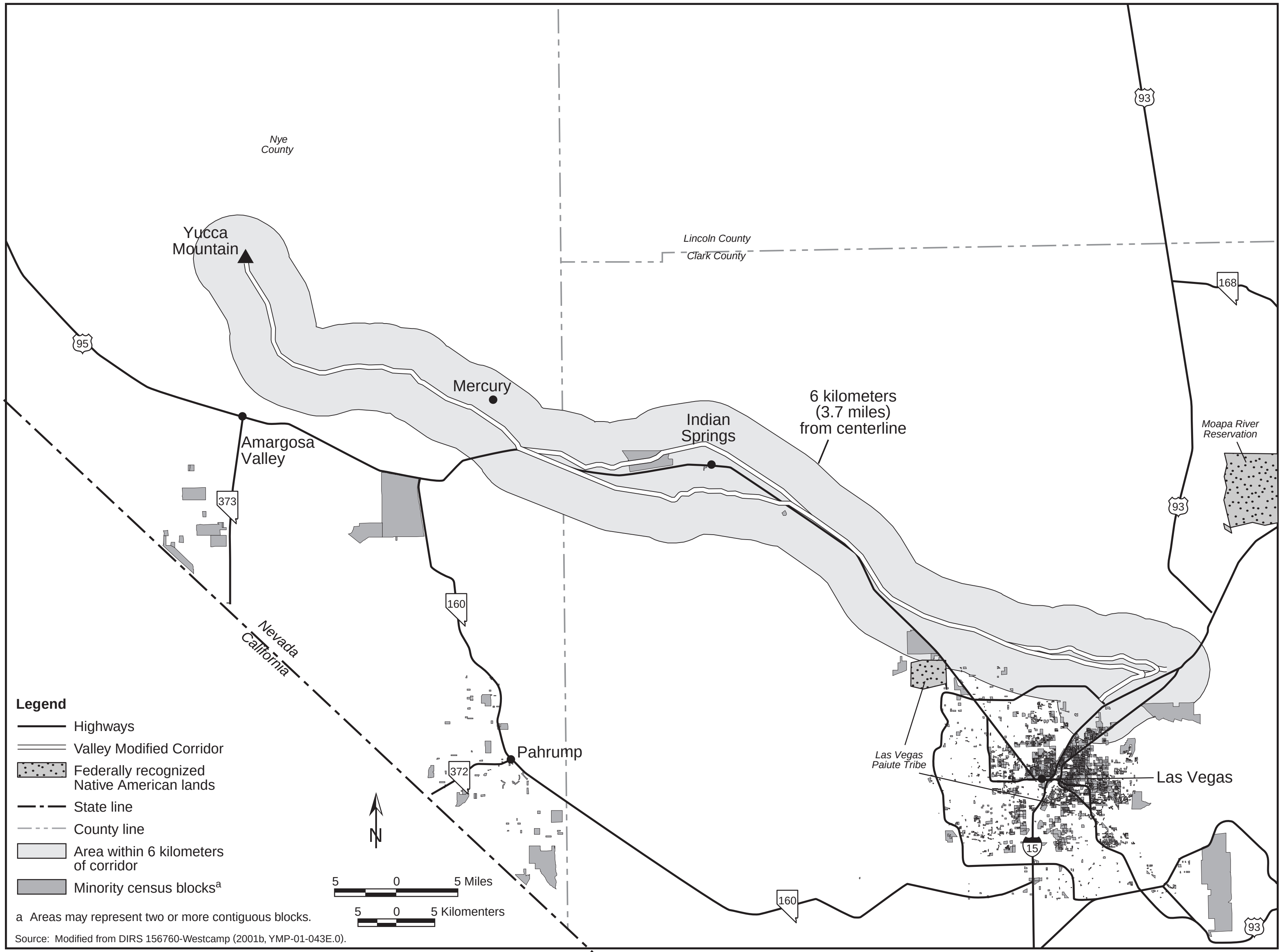


Figure J-25. Nevada minority census blocks in relation to the Valley Modified Corridor.

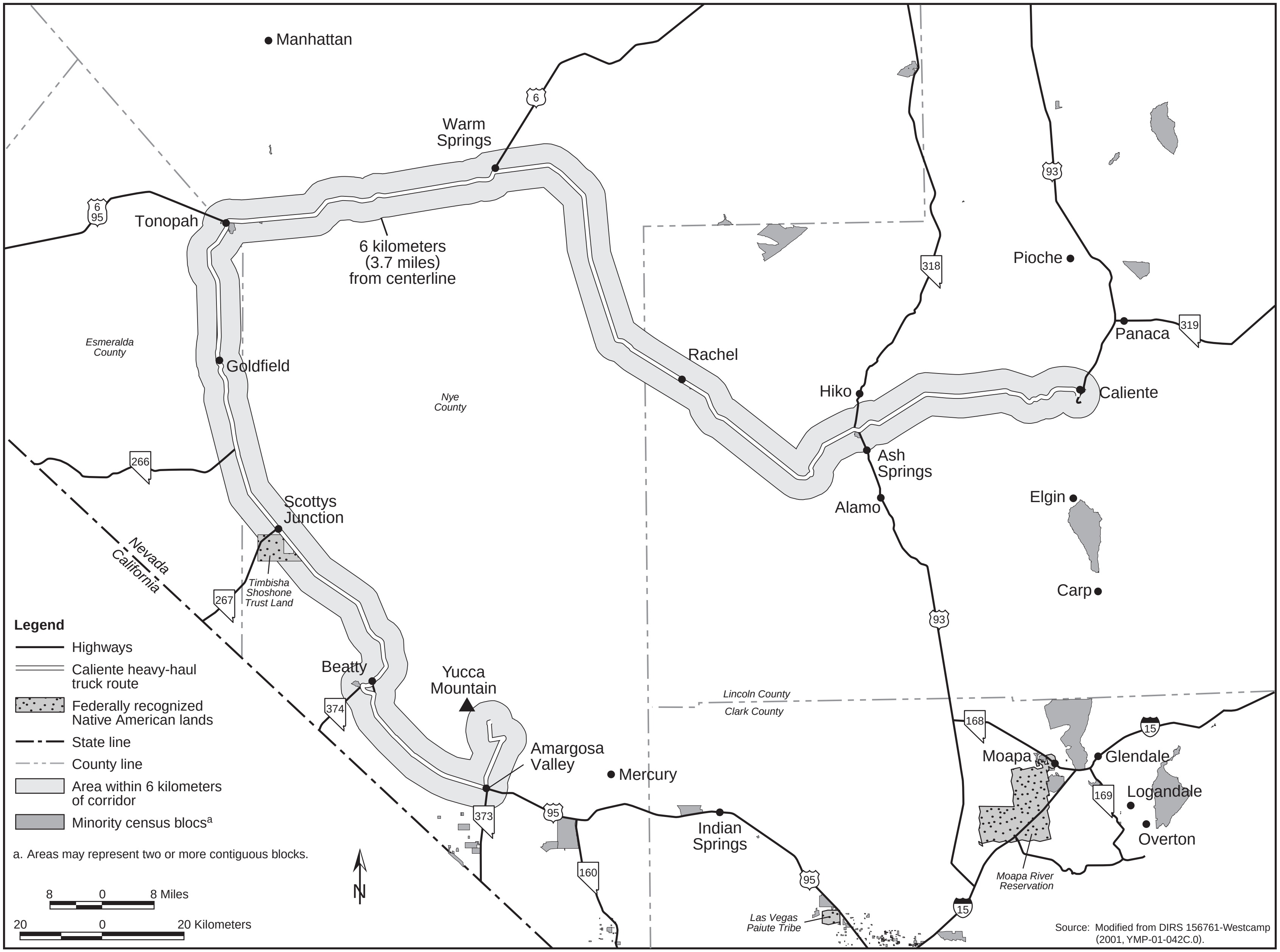


Figure J-26. Nevada minority census blocks in relation to the Caliente heavy-haul truck implementing alternative.

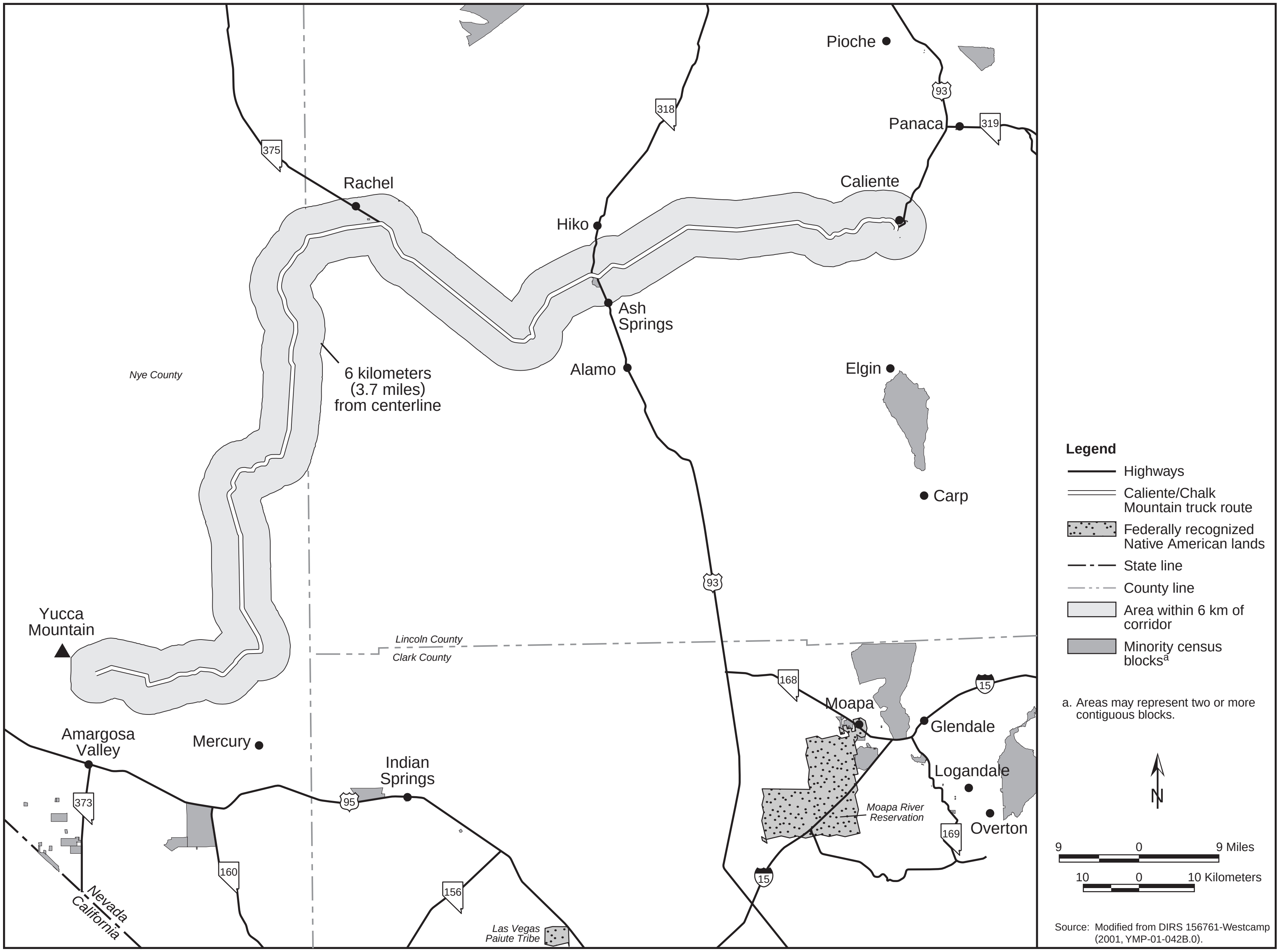


Figure J-27. Nevada minority census blocks in relation to the Caliente/Chalk Mountain route for heavy-haul trucks.

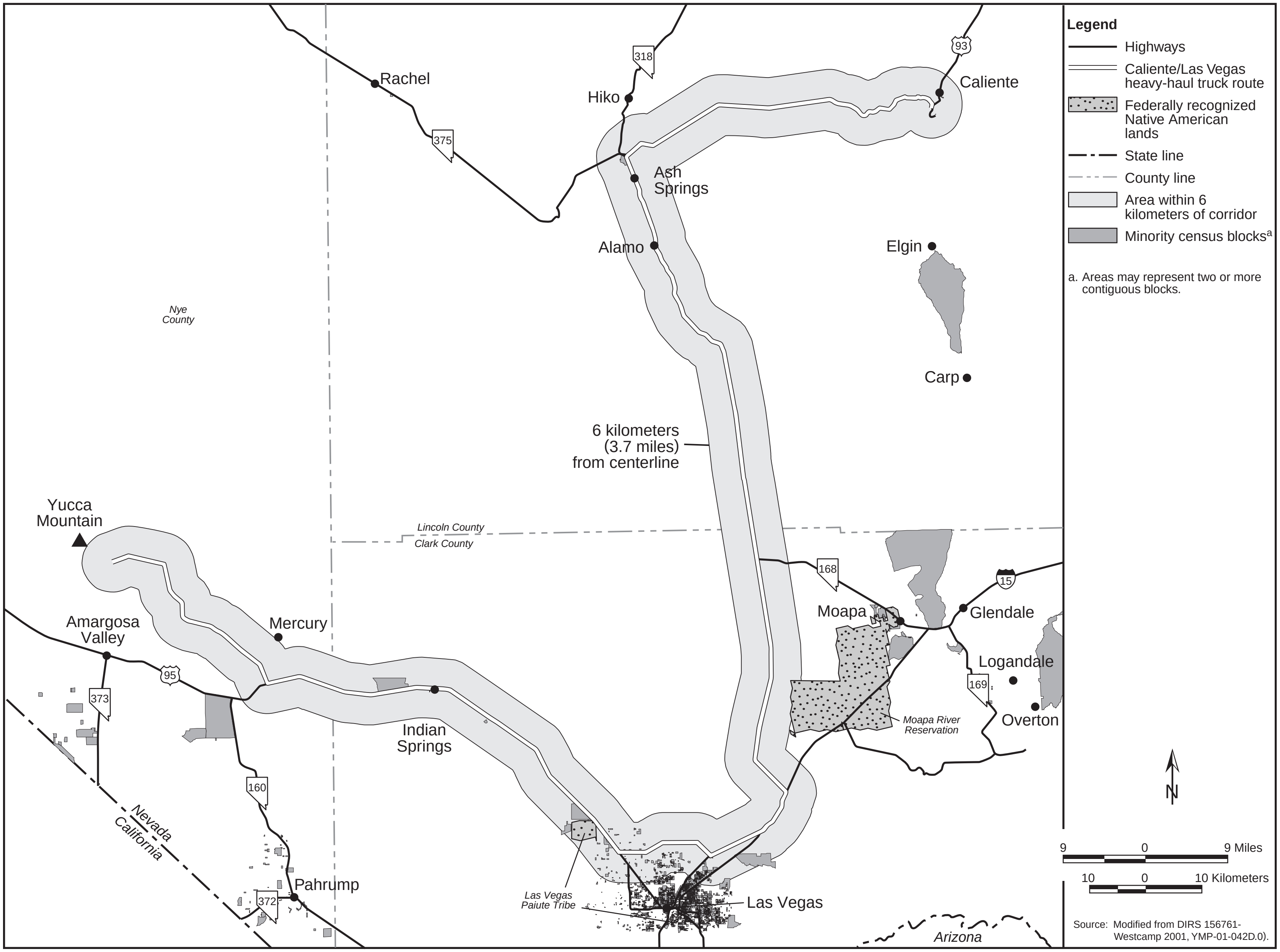


Figure J-28. Nevada minority census blocks in relation to the Caliente/Las Vegas route for heavy-haul trucks.

Table J-46. Nevada routing sensitivity cases analyzed for a legal-weight truck.

Case	Description
Case 1	To Yucca Mountain via Barstow, California, using I-15 to Nevada 160 to Nevada 160 (Nevada D and F)
Case 2	To Yucca Mountain via Barstow using I-15 to California route 127 to Nevada 373 to US 95 (Nevada C)
Case 3	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to California 127 to Nevada 373 and U.S. 95 (Nevada E)
Case 4	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to Nevada 160 (variation of Nevada E)
Case 5	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to U.S. 6 to U.S. 95 (Nevada B)
Case 6	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to Nevada 318 to U.S. 93 to I-15 to the Las Vegas Beltway to U.S. 95 (Nevada A)
Case 7	To Yucca Mountain via Las Vegas using I-15 (for shipments entering Nevada at both the Arizona and California borders) to U.S. 95 (Spaghetti Bowl interchange)

J.3.2 ANALYSIS OF INCIDENT-FREE TRANSPORTATION IN NEVADA

The analysis of incident-free impacts to populations in Nevada addressed transportation through urban, suburban, and rural population zones. The population densities used in the analysis were determined using Geographic Information System methods, population data from the 1990 Census, and projected populations along the Las Vegas Beltway (DIRS 155112-Berger 2000, pp. 59 to 64). The analysis extrapolated impacts to account for population growth to 2035. The populations within the 800-meter (0.5-mile) regions of influence used to evaluate the impacts of incident-free transportation for legal-weight truck, heavy-haul truck, and rail shipments are listed in Table J-35. The table lists the estimated 2035 populations.

Average highway vehicle densities for Nevada were calculated from vehicle traffic counts on Interstate and primary U.S. highways in Nevada counties that would be used for transporting spent nuclear fuel and high-level radioactive waste (DIRS 156930-NDOT 2001, all). The analysis used the average speed of trains on a branch rail line in Nevada from (DIRS 101214-CRWMS M&O 1996, Volume 1, Section 4, Branch Line Operations Plan). Heavy-haul trucks in Nevada would be escorted. The analysis assumed that heavy-haul truck shipments would originate in Caliente, Nevada, and would stop overnight en route to the repository. Input parameters for analysis of incident-free transportation in Nevada that differ from, or are additional to, values used to analyze impacts outside the State, are listed in Table J-49. Parameters not listed in this table are the same as those listed in Tables J-15 and J-17. Unit risk factors for incident-free transportation in Nevada are listed in Table J-50.

Results for incident-free transportation of spent nuclear fuel and high-level radioactive waste for Inventory Modules 1 and 2 are presented in Section J.3.4.

J.3.3 ANALYSIS OF TRANSPORTATION ACCIDENT SCENARIOS IN NEVADA

Section J.1.4 discusses the methodology for estimating the risks of accidents that could occur during rail and truck transportation of spent nuclear fuel and high-level radioactive waste. Section J.3.5 describes the results of the accident risk analysis for Inventory Modules 1 and 2.

J.3.3.1 Intermodal Transfer Station Accident Methodology

Shipping casks would arrive at an intermodal transfer station in Nevada by rail, and a gantry crane would transfer them from the railcars to heavy-haul trucks for transportation to the repository. The casks, which would not be opened or altered in any way at the intermodal transfer station, would be certified by the Nuclear Regulatory Commission and would be designed for accident conditions specified in 10 CFR Part 71. Impact limiters, which would protect casks against collisions during transportation, would remain in place during transfer operations at the intermodal transfer station.

Table J-46. Nevada routing sensitivity cases analyzed for a legal-weight truck.

Case	Description
Case 1	To Yucca Mountain via Barstow, California, using I-15 to Nevada 160 to Nevada 160 (Nevada D and F)
Case 2	To Yucca Mountain via Barstow using I-15 to California route 127 to Nevada 373 to US 95 (Nevada C)
Case 3	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to California 127 to Nevada 373 and U.S. 95 (Nevada E)
Case 4	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to Nevada 160 (variation of Nevada E)
Case 5	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to U.S. 6 to U.S. 95 (Nevada B)
Case 6	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to Nevada 318 to U.S. 93 to I-15 to the Las Vegas Beltway to U.S. 95 (Nevada A)
Case 7	To Yucca Mountain via Las Vegas using I-15 (for shipments entering Nevada at both the Arizona and California borders) to U.S. 95 (Spaghetti Bowl interchange)

J.3.2 ANALYSIS OF INCIDENT-FREE TRANSPORTATION IN NEVADA

The analysis of incident-free impacts to populations in Nevada addressed transportation through urban, suburban, and rural population zones. The population densities used in the analysis were determined using Geographic Information System methods, population data from the 1990 Census, and projected populations along the Las Vegas Beltway (DIRS 155112-Berger 2000, pp. 59 to 64). The analysis extrapolated impacts to account for population growth to 2035. The populations within the 800-meter (0.5-mile) regions of influence used to evaluate the impacts of incident-free transportation for legal-weight truck, heavy-haul truck, and rail shipments are listed in Table J-35. The table lists the estimated 2035 populations.

Average highway vehicle densities for Nevada were calculated from vehicle traffic counts on Interstate and primary U.S. highways in Nevada counties that would be used for transporting spent nuclear fuel and high-level radioactive waste (DIRS 156930-NDOT 2001, all). The analysis used the average speed of trains on a branch rail line in Nevada from (DIRS 101214-CRWMS M&O 1996, Volume 1, Section 4, Branch Line Operations Plan). Heavy-haul trucks in Nevada would be escorted. The analysis assumed that heavy-haul truck shipments would originate in Caliente, Nevada, and would stop overnight en route to the repository. Input parameters for analysis of incident-free transportation in Nevada that differ from, or are additional to, values used to analyze impacts outside the State, are listed in Table J-49. Parameters not listed in this table are the same as those listed in Tables J-15 and J-17. Unit risk factors for incident-free transportation in Nevada are listed in Table J-50.

Results for incident-free transportation of spent nuclear fuel and high-level radioactive waste for Inventory Modules 1 and 2 are presented in Section J.3.4.

J.3.3 ANALYSIS OF TRANSPORTATION ACCIDENT SCENARIOS IN NEVADA

Section J.1.4 discusses the methodology for estimating the risks of accidents that could occur during rail and truck transportation of spent nuclear fuel and high-level radioactive waste. Section J.3.5 describes the results of the accident risk analysis for Inventory Modules 1 and 2.

J.3.3.1 Intermodal Transfer Station Accident Methodology

Shipping casks would arrive at an intermodal transfer station in Nevada by rail, and a gantry crane would transfer them from the railcars to heavy-haul trucks for transportation to the repository. The casks, which would not be opened or altered in any way at the intermodal transfer station, would be certified by the Nuclear Regulatory Commission and would be designed for accident conditions specified in 10 CFR Part 71. Impact limiters, which would protect casks against collisions during transportation, would remain in place during transfer operations at the intermodal transfer station.

Table J-47. Comparison of national impacts from the sensitivity analyses.

Impact	Base case	Case 1 Barstow via Nevada 160	Case 2 Barstow via California 127	Case 3 Needles via Nevada 160	Case 4 Needles via U.S. 95	Case 5 Wendover via U.S. 95	Case 6 Wendover via Las Vegas Beltway	Case 7 I-15 and U.S. 95 (Spaghetti Bowl)
Public incident-free dose (person-rem)	5,000	5,200	5,100	4,900	5,000	4,600	4,800	5,100
Occupational incident-free dose (person-rem)	14,000	15,000	15,000	14,000	14,000	15,000	15,000	14,000
Nonradioactive pollution health effects	0.93	0.93	0.93	0.89	0.88	0.79	0.81	1.1
Public incident-free risk of latent cancer fatality	2.5	2.6	2.6	2.4	2.5	2.3	2.4	2.6
Occupational incident-free risk of latent cancer fatality	5.6	6	5.8	5.6	5.7	5.9	5.9	5.6
Radiological accident risk (person-rem)	0.46	0.36	0.35	0.35	0.35	0.39	0.4	0.52
Radiological accident risk of latent cancer fatality	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0003
Traffic fatalities	4.5	4.5	4.2	4.3	4.2	4.9	5	4.5

Table J-48. Comparison of Nevada impacts from the sensitivity analyses.

Impact	Base case	Case 1 Barstow via Nevada 160	Case 2 Barstow via California 127	Case 3 Needles via Nevada 160	Case 4 Needles via U.S. 95	Case 5 Wendover via U.S. 95	Case 6 Wendover via Las Vegas Beltway	Case 7 I-15 and U.S. 95 (Spaghetti Bowl)
Public incident-free dose (person-rem)	340	180	35	170	83	360	490	480
Occupational incident-free dose (person-rem)	1,900	1,800	1,200	1,800	1,400	3,400	3,500	1,900
Nonradioactive pollution health effects	0.09	0.01	<0.005	0.01	<0.005	0.03	0.04	0.21
Public incident-free risk of latent cancer fatality	0.17	0.09	0.02	0.08	0.04	0.18	0.24	0.24
Occupational incident-free risk of latent cancer fatality	0.75	0.72	0.47	0.7	0.54	1.4	1.4	0.74
Radiological accident risk (person-rem)	0.052	0.005	0.002	0.004	0.002	0.015	0.027	0.11
Radiological accident risk of latent cancer fatality	0.000026	0.000003	0.000001	0.000002	0.000001	0.000008	0.000013	0.000055
Traffic fatalities	0.5	0.4	0.1	0.4	0.2	1.3	1.3	0.5

Table J-49. Input parameters and parameter values used for incident-free Nevada truck and rail transportation different from national parameters.

Parameter	Legal-weight truck	Rail	Heavy-haul truck
Speed (kilometers per hour)[a]			
Rural		50	
One-way traffic count (vehicles per hour)			
Rural	(b)		
Suburban	(b)		
Urban	(b)		
Truck crew dose at walkaround inspections			
Distance of crew from cargo (meters)[c]			30
Truck escort dose at walkaround inspections			
Distance of one inspector (meters)			1
Distance of 3 other escorts (meters)			60
Guards at overnight stop[d]			
Distance of 4 guards from cargo (meters)			60
Time of overnight stop (hours)			12

a. To convert kilometers to miles, multiply by 0.62137.
b. County-specific average traffic counts (DIRS 156930-NDOT 2001, all)
c. To convert meters to feet, multiply by 3.2808.
d. Crew and escorts are far enough away from the cargo and shielded sufficiently that they receive no dose from the cargo during the overnight stop. Number of guards and length of overnight stop are assumptions for analysis purposes.

Table J-50. Per-shipment unit risk factors for incident-free transportation of spent nuclear fuel and high-level radioactive waste in Nevada.

Factor	Heavy-haul truck	Rail	Legal-weight truck
Public			
Off-link [rem per (persons per square kilometers) per kilometer]			
Rural	6.24×10^{-8}	5.01×10^{-8}	2.89×10^{-8}
Suburban	6.24×10^{-8}	6.24×10^{-8}	3.18×10^{-8}
Urban	6.24×10^{-8}	1.04×10^{-7}	3.18×10^{-8}
On-link (person-rem per kilometer)[a]			
Rural	1.46×10^{-4}	2.00×10^{-7}	1.38×10^{-5}
Suburban	1.12×10^{-4}	1.55×10^{-6}	3.89×10^{-5}
Urban	5.40×10^{-4}	4.29×10^{-6}	1.87×10^{-4}
Residents near rest/refueling stops (rem per (persons per square kilometer) per kilometer)			
Rural	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Suburban	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Urban	3.96×10^{-9}	1.24×10^{-7}	5.50×10^{-9}
Residents near classification stops [rem per (persons per square kilometer)]			
Suburban	1.59×10^{-5}		
Public near rest/refueling stops (person-rem per kilometer)			7.86×10^{-6}
Workers			
Classification stop (person-rem)		8.07×10^{-3}	
In-transit stop (person-rem per kilometer)		1.45×10^{-5}	
In moving vehicle (person-rem per kilometer)			
Rural	5.54×10^{-6}		4.52×10^{-5}
Suburban	5.54×10^{-6}		4.76×10^{-5}
Urban	5.54×10^{-6}		4.76×10^{-5}
Crew, walkaround inspection (person-rem per kilometer)	6.27×10^{-7}		1.93×10^{-5}
Escort, walkaround inspection (person-rem per kilometer)	1.50×10^{-5}		
Guards at overnight stops (person-rem)	2.62×10^{-3}		

a. Listed values for on-link unit risk factors are based on Clark County traffic counts. The analysis used country-specific counts for each country through which shipments would pass.

DOE performed an accident screening process to identify credible accidents that could occur at an intermodal transfer station with the potential for compromising the integrity of the casks and releasing radioactive material. The external events listed in Table J-51 were considered, along with an evaluation of their potential applicability.

As indicated from Table J-51, the only accident-initiating event identified from among the feasible external events was the aircraft crash. Such events would be credible only for casks being handled or on transport vehicles at an intermodal transfer station in the Las Vegas area (Apex/Dry Lake or Sloan/Jean).

For a station in the Las Vegas area, an aircraft crash would be from either commercial aircraft operations at McCarran airport or military operations from Nellis Air Force Base.

Among the internal events, the only potential accident identified was a drop of the cask during transfer operations. This accident would bound the other events considered, including drops from the railcar or truck (less fall height would be involved than during the transfer operations). Collisions, derailments, and other accidents involving the transport vehicles at the intermodal transfer station would not damage the casks due to the requirement that they be able to withstand high-speed impacts and the low velocities of the transport vehicles at the intermodal transfer station.

Accident Analysis

1. *Cask Drop Accident.* The only internal event retained after the screening process was a failure of the gantry crane (due to mechanical failure or human error) during the transfer of a shipping cask from a railcar to a heavy-haul truck. The maximum height between the shipping cask and the ground during the transfer operation would be less than 6 meters (19 feet) (DIRS 104849-CRWMS M&O 1997, all). The casks would be designed to withstand a 9-meter (30-foot) drop. Therefore, the cask would be unlikely to fail during the event, especially because the impact energy from the 6-meter drop would be only 65 percent of the minimum design requirement.

2. *Aircraft Crash Accident.* This section, including Tables J-52 and J-53, has been moved to Volume IV of this EIS.

J.3.4 IMPACTS IN NEVADA FROM INCIDENT-FREE TRANSPORTATION FOR INVENTORY MODULES 1 AND 2

This section presents the analysis of impacts to occupational and public health and safety in Nevada from incident-free transportation of spent nuclear fuel and high-level radioactive waste in Inventory Modules 1 and 2. The analysis assumed that the routes, population densities, and shipment characteristics (for example, radiation from shipping casks) for shipments under the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference was the projected number of shipments that would travel to the repository.

The following sections provide detailed information on the range of potential impacts to occupational and public safety and health from incident-free transportation of Modules 1 and 2 that result from legal-weight trucks and the 10 alternative transportation routes considered in Nevada. National impacts of incident-free transportation of Modules 1 and 2 incorporating Nevada impacts are discussed together with other cumulative impacts in Chapter 8.

J.3.4.1 Mostly Legal-Weight Truck Scenario

Tables J-54 and J-55 list estimated incident-free impacts in Nevada for the mostly legal-weight truck scenario for shipments of materials included in Inventory Modules 1 and 2.

DOE performed an accident screening process to identify credible accidents that could occur at an intermodal transfer station with the potential for compromising the integrity of the casks and releasing radioactive material. The external events listed in Table J-51 were considered, along with an evaluation of their potential applicability.

As indicated from Table J-51, the only accident-initiating event identified from among the feasible external events was the aircraft crash. Such events would be credible only for casks being handled or on transport vehicles at an intermodal transfer station in the Las Vegas area (Apex/Dry Lake or Sloan/Jean).

For a station in the Las Vegas area, an aircraft crash would be from either commercial aircraft operations at McCarran airport or military operations from Nellis Air Force Base.

Among the internal events, the only potential accident identified was a drop of the cask during transfer operations. This accident would bound the other events considered, including drops from the railcar or truck (less fall height would be involved than during the transfer operations). Collisions, derailments, and other accidents involving the transport vehicles at the intermodal transfer station would not damage the casks due to the requirement that they be able to withstand high-speed impacts and the low velocities of the transport vehicles at the intermodal transfer station.

Accident Analysis

1. *Cask Drop Accident.* The only internal event retained after the screening process was a failure of the gantry crane (due to mechanical failure or human error) during the transfer of a shipping cask from a railcar to a heavy-haul truck. The maximum height between the shipping cask and the ground during the transfer operation would be less than 6 meters (19 feet) (DIRS 104849-CRWMS M&O 1997, all). The casks would be designed to withstand a 9-meter (30-foot) drop. Therefore, the cask would be unlikely to fail during the event, especially because the impact energy from the 6-meter drop would be only 65 percent of the minimum design requirement.

2. *Aircraft Crash Accident.* This section, including Tables J-52 and J-53, has been moved to Volume IV of this EIS.

J.3.4 IMPACTS IN NEVADA FROM INCIDENT-FREE TRANSPORTATION FOR INVENTORY MODULES 1 AND 2

This section presents the analysis of impacts to occupational and public health and safety in Nevada from incident-free transportation of spent nuclear fuel and high-level radioactive waste in Inventory Modules 1 and 2. The analysis assumed that the routes, population densities, and shipment characteristics (for example, radiation from shipping casks) for shipments under the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference was the projected number of shipments that would travel to the repository.

The following sections provide detailed information on the range of potential impacts to occupational and public safety and health from incident-free transportation of Modules 1 and 2 that result from legal-weight trucks and the 10 alternative transportation routes considered in Nevada. National impacts of incident-free transportation of Modules 1 and 2 incorporating Nevada impacts are discussed together with other cumulative impacts in Chapter 8.

J.3.4.1 Mostly Legal-Weight Truck Scenario

Tables J-54 and J-55 list estimated incident-free impacts in Nevada for the mostly legal-weight truck scenario for shipments of materials included in Inventory Modules 1 and 2.

Table J-51. Screening analysis of external events considered potential accident initiators at intermodal transfer station.

Event	Applicability
Aircraft crash	Retained for further evaluation
Avalanche	(a)
Coastal erosion	(a)
Dam failure	See flooding
Debris avalanching	(a)
Dissolution	(b)
Epeirogenic displacement (tilting of the earth's crust)	(c)
Erosion	(b)
Extreme wind	(c)
Extreme weather	(e)
Fire (range)	(b)
Flooding	(d)
Denudation (loss of land cover)	(b)
Fungus, bacteria, algae	(b)
Glacial erosion	(b)
High lake level	(b)
High tide	(a)
High river stage	See flooding
Hurricane	(a)
Inadvertent future intrusion	(b)
Industrial activity	Bounded by aircraft crash
Intentional future intrusion	(b)
Lightning	(c)
Loss of off/on site power	(c)
Low lake level	(b)
Meteorite impact	(e)
Military activity	Retained for further evaluation
Orogenic diastrophism (tectonic ground movement)	(e)
Pipeline accident	(b)
Rainstorm	See flooding
Sandstorm	(c)
Sedimentation	(b)
Seiche (sudden water-level change)	(a)
Seismic activity, uplifting	(c)
Seismic activity, earthquake	(c)
Seismic activity, surface fault	(c)
Seismic activity, subsurface fault	(c)
Static fracturing	(b)
Stream erosion	(b)
Subsidence	(c)
Tornado	(c)
Tsunami (tidal wave)	(a)
Undetected past intrusions	(b)
Undetected geologic features	(b)
Undetected geologic processes	(c)
Volcanic eruption	(e)
Volcanism, magmatic activity	(e)
Volcanism, ash flow	(c)
Volcanism, ash fall	(b)
Waves (aquatic)	(a)

a. Conditions at proposed sites do not allow event.
b. Not a potential accident initiator.
c. Bounded by cask drop accident considered in the internal events analysis.
d. Shipping cask designed for event.
e. Not credible, see evaluation for repository.

Table J-54. Population doses and radiological impacts from incident-free Nevada transportation for mostly legal-weight truck scenario–Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1			
Involved worker			
Collective dose (person-rem)	3,700	21	3,700
Estimated latent cancer fatalities	1.5	0.008	1.5
Public			
Collective dose (person-rem)	680	10	690
Estimated latent cancer fatalities	0.34	0.005	0.35
Module 2			
Involved worker			
Collective dose (person-rem)	3,800	23	3,900
Estimated latent cancer fatalities	1.5	0.009	1.5
Public			
Collective dose (person-rem)	700	13	710
Estimated latent cancer fatalities	0.35	0.007	0.36

a. Impacts are totals for shipments over 38 years.
b. Includes impacts at intermodal transfer stations.
c. Totals might differ from sums due to rounding.

Table J-55. Population health impacts from vehicle emissions during incident-free Nevada transportation for the mostly legal-weight truck scenario–Modules 1 and 2.[a]

Vehicle emission-related fatalities	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1	0.17	0.0069	0.18
Module 2	0.18	0.0081	0.19

a. Impacts are totals for shipments over 38 years.
b. Includes heavy-haul truck shipments in Nevada.
c. Totals might differ from sums due to rounding.

J.3.4.2 Nevada Rail Implementing Alternatives

Table J-56 lists the range of estimated incident-free impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations for a branch line in each of the five possible rail corridors DOE is evaluating. These include the impacts of about 3,100 legal-weight truck shipments from commercial sites that could not use rail casks to ship spent nuclear fuel.

J.3.4.3 Nevada Heavy-Haul Truck Implementing Alternatives

Radiological Impacts

Intermodal Transfer Station Impacts. Involved worker exposures (the analysis assumed that the noninvolved workers would receive no radiation exposure and thus required no further analysis) would occur during both inbound (to the repository) and outbound (to the 77 sites) portions of the shipment campaign. DOE used the same involved worker level of effort it used in the analysis of intermodal transfer station worker industrial safety impacts to estimate collective involved worker radiological impacts (that is, 16 full-time equivalents per year). The collective worker radiation doses were adapted from a study (DIRS 104791-DOE 1992, all) of a spent nuclear fuel transportation system, which was also performed for the commercial sites. That study found that the collective worker doses that could be incurred during similar inbound and outbound transfer operations of a single loaded (with commercial

Table J-56. Radiological and nonradiological impacts from incident-free Nevada transportation for the rail implementing alternatives–Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments	Total[b]
Involved worker			
Collective dose (person-rem)	110	1,300 - 1,900	1,400 - 2,000
Estimated latent cancer fatalities	0.04	0.52 - 0.76	0.56 - 0.8
Public			
Collective dose (person-rem)	19	106 - 640	130 - 659
Estimated latent cancer fatalities	0.01	0.05 - 0.32	0.07 - 0.33
Estimated vehicle emission-related fatalities	0.0046	0.012 - 0.38	0.016 - 0.38

a. Impacts are totals for shipments over 38 years.
b. Totals might differ from sums due to rounding.

spent nuclear fuel) and unloaded cask were approximately 0.027 and 0.00088 person-rem per cask, respectively, as listed in Table J-57.

Table J-57. Collective worker doses (person-rem) from transportation of a single cask.[a,b]

Inbound	Inbound CD[b]	Outbound	Outbound CD
Receive transport vehicle and loaded cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	6.3×10^{-3}	Receive transport vehicle and empty cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	0.0
Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	1.4×10^{-3}	Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	5.4×10^{-4}
Move cask to receiving and handling area.	9.2×10^{-5}	Move cask to receiving and handling area.	8.0×10^{-6}
Remove cask from carrier and place on cask cart.	4.3×10^{-3}	Remove cask from carrier and place on cask cart.	2.2×10^{-4}
Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	7.0×10^{-4}	Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	3.3×10^{-5}
Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	1.4×10^{-2}	Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	8.3×10^{-5}
Notify appropriate organizations of the shipment’s departure.	0.0	Notify appropriate organizations of the shipment’s departure.	0.0
Total	2.7×10^{-2}	*Total*	8.8×10^{-4}

a. Adapted from DIRS 104791-DOE (1992, Table 4.2).
b. Values are rounded to two significant figures; therefore, totals might differ from sums of values.
c. CD = collective dose (person-rem per cask).

The analysis used these inbound and outbound collective dose factors to calculate the involved worker impacts listed in Table J-58 for Module 1 and Module 2 inventories in the same manner it used for commercial power reactor spent nuclear fuel impacts. The number of inbound and outbound shipments for Module 1 and Module 2 inventories is from Section J.1.2. The worker impacts reflect two-way operations.

Incident-Free Transportation. Table J-59 lists the range of estimated incident-free impacts in Nevada for the use of heavy-haul trucks to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations on each of the five possible highway routes in Nevada DOE is evaluating. These include impacts of about 3,100 legal-weight truck shipments from commercial sites under Modules 1 and 2 that could not ship spent nuclear fuel using rail casks while operational.

Table J-58. Doses and radiological health impacts to involved workers from intermodal transfer station operations – Modules 1 and 2.[a,b]

Group	Module 1		Module 2	
	Dose (millirem)	Latent cancer fatality	Dose (millirem)	Latent cancer fatality
Maximally exposed individual worker	12	0.005[c]	12	0.005
Involved worker population	500	0.20[d]	520	0.21

a. Includes estimated impacts from handling 300 shipments of Naval spent nuclear fuel that would be shipped by rail under the mostly legal-weight truck transportation scenario.
b. Totals for 38 years of operations.
c. The estimated probability of a latent cancer fatality in an exposed individual.
d. The estimated number of latent cancer fatalities in an exposed involved worker population.

Table J-59. Radiological and nonradiological health impacts from incident-free transportation for the heavy-haul truck implementing alternatives – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Total[c]
Involved worker			
Collective dose (person-rem)	110	2,100 - 3,100	2,200 - 3,300
Estimated latent cancer fatalities	0.04	0.85 - 1.3	0.89 - 1.3
Public			
Collective dose (person-rem)	19	100 - 580	120 - 600
Estimated latent cancer fatalities	0.01	0.05 - 0.29	0.06 - 0.3
Estimated vehicle emission-related fatalities	0.0046	0.0096 - 0.35	0.014 - 0.35

a. Impacts are totals for 38 years.
b. Includes impacts to workers at an intermodal transfer station.
c. Totals might differ from sums due to rounding.

J.3.5 IMPACTS IN NEVADA FROM TRANSPORTATION ACCIDENTS FOR INVENTORY MODULES 1 AND 2

The analysis assumed that the routes, population densities, and shipment characteristics (for example, assumed radioactive material contents of shipping casks) for the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of shipments that would travel to the repository. As listed in Table J-1, Module 2 would include about 3 percent more shipments than Module 1.

J.3.5.1 Mostly Legal-Weight Truck Scenario

Radiological Impacts

The analysis estimated the radiological impacts of accidents in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. The radiological health impacts associated with both Modules 1 and 2 would be 0.1 person-rem (see Table J-60). These impacts would occur over 38 years in a population of more than 1 million people who lived within 80 kilometers (50 miles) of the Nevada routes that DOE would use. This dose risk would lead to less than 1 chance in 1,000 of an additional cancer fatality in the exposed population. For comparison, in Nevada about 240,000 in a population of 1 million people would suffer fatal cancers from other causes (DIRS 153066-Murphy 2000, p. 83).

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste by legal-weight trucks in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. It estimated that there would be

Table J-58. Doses and radiological health impacts to involved workers from intermodal transfer station operations – Modules 1 and 2.[a,b]

Group	Module 1		Module 2	
	Dose (millirem)	Latent cancer fatality	Dose (millirem)	Latent cancer fatality
Maximally exposed individual worker	12	0.005[c]	12	0.005
Involved worker population	500	0.20[d]	520	0.21

a. Includes estimated impacts from handling 300 shipments of Naval spent nuclear fuel that would be shipped by rail under the mostly legal-weight truck transportation scenario.
b. Totals for 38 years of operations.
c. The estimated probability of a latent cancer fatality in an exposed individual.
d. The estimated number of latent cancer fatalities in an exposed involved worker population.

Table J-59. Radiological and nonradiological health impacts from incident-free transportation for the heavy-haul truck implementing alternatives – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Total[c]
Involved worker			
Collective dose (person-rem)	110	2,100 - 3,100	2,200 - 3,300
Estimated latent cancer fatalities	0.04	0.85 - 1.3	0.89 - 1.3
Public			
Collective dose (person-rem)	19	100 - 580	120 - 600
Estimated latent cancer fatalities	0.01	0.05 - 0.29	0.06 - 0.3
Estimated vehicle emission-related fatalities	0.0046	0.0096 - 0.35	0.014 - 0.35

a. Impacts are totals for 38 years.
b. Includes impacts to workers at an intermodal transfer station.
c. Totals might differ from sums due to rounding.

J.3.5 IMPACTS IN NEVADA FROM TRANSPORTATION ACCIDENTS FOR INVENTORY MODULES 1 AND 2

The analysis assumed that the routes, population densities, and shipment characteristics (for example, assumed radioactive material contents of shipping casks) for the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of shipments that would travel to the repository. As listed in Table J-1, Module 2 would include about 3 percent more shipments than Module 1.

J.3.5.1 Mostly Legal-Weight Truck Scenario

Radiological Impacts

The analysis estimated the radiological impacts of accidents in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. The radiological health impacts associated with both Modules 1 and 2 would be 0.1 person-rem (see Table J-60). These impacts would occur over 38 years in a population of more than 1 million people who lived within 80 kilometers (50 miles) of the Nevada routes that DOE would use. This dose risk would lead to less than 1 chance in 1,000 of an additional cancer fatality in the exposed population. For comparison, in Nevada about 240,000 in a population of 1 million people would suffer fatal cancers from other causes (DIRS 153066-Murphy 2000, p. 83).

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste by legal-weight trucks in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. It estimated that there would be

Table J-60. Accident impacts for Modules 1 and 2 – Nevada transportation.[a]

Transportation scenario	Dose risk (person-rem)	Latent cancer fatalities	Traffic fatalities
Legal-weight truck	0.1[b]	0.0001	0.97
Legal-weight truck for the mostly rail scenario	0.003	0.000001	0.03
Mostly rail (Nevada rail implementing alternatives)			
Caliente	0.0012	0.000001	0.12
Carlin	0.0026	0.000001	0.16
Caliente-Chalk Mountain	0.0011	0.000001	0.08
Jean	0.01	0.000005	0.09
Valley Modified	0.0017	0.000001	0.08
Mostly rail (Nevada heavy-haul implementing alternatives)			
Caliente	0.015	0.000008	1.2
Caliente/Chalk Mountain	0.002	0.000001	0.62
Caliente/Las Vegas	0.092	0.00005	0.83
Apex/Dry Lake	0.091	0.00005	0.44
Sloan/Jean	0.2	0.0001	0.46

a. Impacts over 38 years.
b. Estimates of dose risk are for the transportation of the materials included in Module 2. Estimates of dose risk for transportation of the materials in Module 1 would be slightly (about 3 percent) lower.

0.97 fatality over 38 years for Module 1 or Module 2 (see Table J-60). The estimate of traffic fatalities includes the risk of fatalities from 300 shipments of naval spent nuclear fuel.

J.3.5.2 Nevada Rail Implementing Alternatives

Industrial Safety Impacts

Table J-61 lists the estimated industrial safety impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. The table lists impacts that would result from operations for a branch line in each of the five possible rail corridors in Nevada that DOE is evaluating.

Table J-61. Rail corridor operation worker physical trauma impacts (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified
Involved workers					
TRC[a]	150	150	150	115	115
LWC[b]	82	82	82	63	63
Fatalities	0.41	0.41	0.41	0.31	0.31
Noninvolved workers[c]					
TRC	9	9	9	7	7
LWC	3	3	3	2	2
Fatalities	0.01	0.01	0.01	0.01	0.01
All workers (totals)[d]					
TRC	160	160	160	120	120
LWC	85	85	85	65	65
Fatalities	0.42	0.42	0.42	0.32	0.32
Traffic fatalities[e]	1.1	1.1	1.1	0.83	0.83

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

The representative workplace loss incidence rate for each impact parameter (as compiled by the Bureau of Labor Statistics) was used as a multiplier to convert the operations crew level of effort to expected industrial safety losses. The involved worker full-time equivalent multiples that DOE would assign to operate each rail corridor each year was estimated to be 36 to 47 full-time equivalents, depending on the corridor for the period of operations [scaled from cost data in DIRS 101214-CRWMS M&O (1996, Appendix E)]. Noninvolved worker full-time equivalent multiples were unavailable, so DOE assumed that the noninvolved worker level of effort would be similar to that for the repository operations work force—about 25 percent of that for involved workers. The Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was multiplied by the involved and noninvolved worker full-time equivalent multiples to project the associated trauma incidence.

The Bureau of Labor Statistics involved worker total recordable case incidence rate, 145,700 total recordable cases in a workforce of 1,739,000 workers (0.084 total recordable case per full-time equivalent) reflects losses in the Trucking and Warehousing sector during the 1998 period of record. The same Bureau of Labor Statistics period of record and industry sector was used to select the involved worker lost workday case incidence rate [80,000 lost workday cases in a workforce of 1,739,000 workers (0.046 lost workday case per full-time equivalent)]. The involved worker fatality incidence rate, 23.4 fatalities in a workforce of 100,000 workers (0.00023 fatality per full-time equivalent) reflects losses in the Transportation and Material Moving Occupations sector during the 1998 period of record.

The noninvolved worker total recordable case incidence rate of 61,000 total recordable cases in a workforce of 3,170,300 workers (0.019 total recordable case per full-time equivalent) reflects losses in the Engineering and Management Services sector during the Bureau of Labor Statistics 1998 period of record. DOE used the same period of record and industry sector to select the noninvolved worker lost workday case incidence rate [22,400 lost workday cases in a workforce of 3,170,300 workers (0.071 lost workday case per full-time equivalent)]. The noninvolved worker fatality incidence rate, 1.6 fatalities in a workforce of 100,000 workers (0.00002 fatality per full-time equivalent) reflects losses in the Managerial and Professional Specialties sector during the 1998 period of record.

Table J-61 lists the results of these industrial safety calculations for the five candidate corridors under Inventory Modules 1 and 2. The table also lists estimates of the number of traffic fatalities that would occur in the course of commuting by workers to and from their construction and operations jobs. These estimates used national statistics for average commute distances [18.5 kilometers (11.5 miles) one-way (DIRS 102064-FHWA 1999, all)] and fatality rates for automobile traffic [1 per 100 million kilometers (1.5 per 100 million miles) (DIRS 148080-BTS 1998, all)].

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accident scenarios in Nevada for the Nevada rail implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the radiological dose risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 3,100 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel in rail casks while operational. The analysis assumed that those sites would upgrade their crane capacity after reactor shutdown to allow the use of rail casks. The risks would occur over 38 years.

Traffic Fatalities

Traffic fatalities from accidents involving transport of spent nuclear fuel and high-level radioactive waste by rail in Nevada were estimated for the Nevada rail implementing alternatives for shipments of materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated number of fatalities that would occur over 38 years for a branch rail line along each of the five candidate rail corridors. These estimates include accident risks in Nevada from about 3,100 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks while operational.

J.3.5.3 Nevada Heavy-Haul Truck Implementing Alternatives

Industrial Safety Impacts

Tables J-62 and J-63 list the estimated industrial safety impacts in Nevada for operations of heavy-haul trucks (principally highway maintenance safety impacts) and operation of an intermodal transfer station that would transfer loaded and unloaded rail casks between rail cars and heavy-haul trucks for shipments of the materials included in Inventory Modules 1 and 2. Table J-62 lists the estimated industrial safety impacts in Nevada for the operation of a heavy-haul route to the Yucca Mountain site. Table J-63 lists impacts that would result from the operation of an intermodal transfer station for any of the five candidate routes DOE is evaluating that heavy-haul trucks could use in Nevada.

Table J-62. Industrial health impacts from heavy-haul truck route operations (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Caliente/Chalk Mountain	Caliente/Las Vegas	Sloan/ Jean	Apex/Dry Lake
Involved workers					
TRC[a]	350	350	320	190	190
LWC[b]	190	190	180	100	100
Fatalities	1.0	1.0	0.9	0.5	0.5
Noninvolved workers[c]					
TRC	20	20	18	11	11
LWC	8	8	7	4	4
Fatalities	0.02	0.02	0.02	0.01	0.01
All workers (totals)[d]					
TRC	370	370	340	200	200
LWC	200	200	180	110	110
Fatalities	0.99	0.99	0.99	0.53	0.53
Traffic fatalities[e]	2.6	2.3	2.6	1.4	1.4

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

Table J-63. Annual physical trauma impacts to workers from intermodal transfer station operations (Module 1 or 2).

Involved workers			Noninvolved workers[a]			All workers		
TRC[b]	LWC[c]	Fatalities	TRC	LWC	Fatalities	TRC	LWC	Fatalities
85	47	0.23	5	2	0.01	90	48	0.24

a. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
b. TRC = total recordable cases of injury and illness.
c. LWC = lost workday cases.

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accidents in Nevada for the Nevada heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2.

Table J-60 lists the radiological dose risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 3,100 legal-weight truck shipments from commercial generating sites that could not ship spent nuclear fuel in rail casks while operational. The risk would occur over 38 years.

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste (including the rail portion of transportation to and from an intermodal transfer station) in Nevada for the heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated number of fatalities that would occur over 38 years for a branch rail line and for each of the five candidate routes for heavy-haul trucks. The estimate for traffic fatalities includes accident risk in Nevada from about 3,100 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks while operational.

J.3.6 IMPACTS FROM TRANSPORTATION OF OTHER MATERIALS

Other types of transportation activities associated with the Proposed Action would involve shipments of materials other than the spent nuclear fuel and high-level radioactive waste discussed in previous sections. These activities would include the transportation of people (commuter transportation). This section evaluates occupational and public health and safety and air quality impacts from the shipment of:

- Construction materials, consumables, and personnel for repository construction and operation, including repository components (disposal containers, emplacement pallets, drip shields, and solar panels).
- Waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste
- Office and laboratory supplies, mail, and laboratory samples

The analysis included potential impacts of transporting these materials for the flexible design, in which the repository would be open for 76 years after emplacement, and for several lower-temperature operating scenarios that would leave the repository open and ventilated for 125 to 300 years, a surface facility that would provide storage during a cooling period, and the use of derated waste packages. The analysis assumed that material would be shipped across the United States to Nevada by rail, but that DOE would not build a rail line to the proposed repository, because the larger number of truck shipments would lead to higher impacts than those for rail shipments, as discussed above. In addition, because the construction schedule for a new rail line would coincide with the schedule for the construction of repository facilities, trucks would deliver materials for repository construction.

Rail service would benefit the delivery of the 11,300 disposal containers from manufacturers. Two 33,000-kilogram (about 73,000-pound) disposal containers and their 700-kilogram (about 1,500-pound) lids (DIRS 155347-CRWMS M&O 1999, all) would be delivered on a railcar—a total of 5,650 railcar deliveries over the 24-year period of the Proposed Action (8,400 railcar deliveries if DOE used 17,000 derated waste packages). These containers would be delivered to the repository along with shipments of spent nuclear fuel and high-level radioactive waste or separately on supply trains along with shipments of materials and equipment.

Disposal container components that would weigh as much as 34 metric tons (37.5 tons) would be transported to Nevada by rail and transferred to overweight trucks for shipment to the repository site. Overweight truck shipments would move the 11,300 (or 17,000 if derated) containers from a railhead to the site. The State of Nevada routinely provides permits to motor carriers for overweight, overdimension generating sites that could not ship spent nuclear fuel in rail casks while operational. The risk would occur over 38 years.

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste (including the rail portion of transportation to and from an intermodal transfer station) in Nevada for the heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated number of fatalities that would occur over 38 years for a branch rail line and for each of the five candidate routes for heavy-haul trucks. The estimate for traffic fatalities includes accident risk in Nevada from about 3,100 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks while operational.

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- Waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste

- Office and laboratory supplies, mail, and laboratory samples

The analysis included potential impacts of transporting these materials for the flexible design, in which the repository would be open for 76 years after emplacement, and for several lower-temperature operating scenarios that would leave the repository open and ventilated for 125 to 300 years, a surface facility that would provide storage during a cooling period, and the use of derated waste packages. The analysis assumed that material would be shipped across the United States to Nevada by rail, but that DOE would not build a rail line to the proposed repository, because the larger number of truck shipments would lead to higher impacts than those for rail shipments, as discussed above. In addition, because the construction schedule for a new rail line would coincide with the schedule for the construction of repository facilities, trucks would deliver materials for repository construction.

Rail service would benefit the delivery of the 11,300 disposal containers from manufacturers. Two 33,000-kilogram (about 73,000-pound) disposal containers and their 700-kilogram (about 1,500-pound) lids (DIRS 155347-CRWMS M&O 1999, all) would be delivered on a railcar—a total of 5,650 railcar deliveries over the 24-year period of the Proposed Action (8,400 railcar deliveries if DOE used 17,000 derated waste packages). These containers would be delivered to the repository along with shipments of spent nuclear fuel and high-level radioactive waste or separately on supply trains along with shipments of materials and equipment.

Disposal container components that would weigh as much as 34 metric tons (37.5 tons) would be transported to Nevada by rail and transferred to overweight trucks for shipment to the repository site. Overweight truck shipments would move the 11,300 (or 17,000 if derated) containers from a railhead to the site. The State of Nevada routinely provides permits to motor carriers for overweight, overdimension loads if the gross vehicle weight does not exceed 58.5 metric tons (64.5 tons) (DIRS 155347-CRWMS M&O 1999, Request #046).

J.3.6.1 Transportation of Personnel and Materials to Repository

The following paragraphs describe impacts that would result from the transportation of construction materials, consumables, repository components, supplies, mail, laboratory samples, and personnel to the repository site during the construction, operation and monitoring, and closure phases of the Proposed Action.

Human Health and Safety

Most construction materials, construction equipment, and consumables would be transported to the Yucca Mountain site on legal-weight trucks. Heavy and overdimensional construction equipment would be delivered by trucks under permits issued by the Nevada Department of Transportation. The analysis assumed that repository components would be manufactured somewhere in the central United States, while other materials and consumables would originate in Nevada. DOE estimates that about 37,000 to 41,000 rail and truck shipments over 5 years would be necessary to transport materials, supplies, and equipment to the site during the construction phase, depending on the operating mode. Surface facilities for aging would require more construction materials.

In addition to construction materials, supplies, equipment, and repository components, trucks would deliver consumables to the repository site. These would include diesel fuel, cement, and other materials that would be consumed in daily operations.

Over the 24-year period of operation, the repository would receive between 6,600 and 10,000 shipments from across the United States, and between 47,000 and 62,000 shipments in Nevada of supplies, materials, equipment, repository components, and consumables, including cement and other materials for underground excavation. The analysis assumed that the Nevada shipments would originate in the Las Vegas metropolitan area. In addition, an estimated 53,000 shipments of office and laboratory supplies and equipment, mail, and laboratory samples would occur during the 24 years of operation. About 27 million to 41 million vehicle kilometers nationally (17 million to 25 million vehicle miles) of travel, and about 34 million to 40 million kilometers (21 million to 25 million miles) in Nevada would be involved. Impacts would include vehicle emissions, consumption of petroleum resources, increased truck traffic on regional highways, and fatalities from accidents. Similarly, there would be about 43 to 760 shipments nationally, and 190,000 to 720,000 shipments in Nevada during the 76-to-300-year monitoring period after emplacement operations and about 35,000 shipments, more than 99 percent in Nevada, during closure activities. Table J-64 summarizes these impacts.

Table J-64. Human health and safety impacts from national and Nevada shipments of material to the repository.

Phase	Kilometers[a] traveled (millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction (5 years)	8.9 - 10	0.15 - 0.21	2.9 - 10	0.019 - 0.022
Emplacement and development (24 years)	61 - 81	2.7 - 3.9	430 - 650	0.14 - 0.19
Monitoring (76 to 300 years)	47 - 170	0.8 - 3.0	13 - 65	0.10 - 0.36
Closure (10 to 17 years)	8.4 - 8.9	0.14 - 0.17	2.2 - 8.1	0.018 - 0.019
Totals[c]	*130 - 270*	*3.8 - 7.2*	*450 - 720*	*0.27 - 0.59*

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

During the construction phase, many employees would use their personal automobiles to travel to construction areas on the repository site and to highway or rail line construction sites. The estimated average annual level of direct employment during repository surface and subsurface construction would be between 1,500 and 1,600 workers, depending on the operating mode. Current Nevada Test Site employees can ride DOE-provided buses to and from work; similarly, buses probably would be available for repository construction workers. The use of buses and car pools would result in an average vehicle occupancy of 8.6 persons per vehicle. Table J-65 summarizes the anticipated number of traffic-accident-related injuries and fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be added congestion at the northwestern Las Vegas Beltway interchange with U.S. Highway 95. Current estimates call for traffic at this interchange during rush hours to be as high as 1,000 vehicles an hour (DIRS 103710-Clark County 1997, Table 3-12, p. 3-43). The additional traffic from repository construction, assuming that the peak traffic would be 3 times the average, would be an estimated 600 vehicles per hour and would add about 35 percent to traffic volume at peak rush hour and would contribute to congestion although congestion in this area would be generally low.

Table J-65. Health impacts and fuel consumption from transportation of construction and operations workers.

Phase	Kilometers[a] traveled (in millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction	51 - 56	0.51 - 0.56	8.5 - 8.7	0.067 - 0.074
Emplacement and development (24 years)	290 - 440	2.9 - 4.4	48 - 73	0.38 - 0.58
Monitoring (76 to 300 years)	87 - 280	0.87 - 2.8	14 - 45	0.11 - 0.36
Closure	48 - 62	0.48 - 0.62	8.0 - 10	0.063 - 0.082
Totals[c]	*480 - 800*	*4.8 - 8.0*	*79 - 130*	*0.63 - 1.1*

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

The average annual employment during emplacement and development operations would be between 1,700 and 2,600 workers. As mentioned above, DOE provides bus service from the Las Vegas area to and from the Nevada Test Site. Table J-65 summarizes the anticipated number of traffic-accident-related fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be increased congestion at the northwestern Las Vegas Beltway interchange with U.S. 95. As many as 600 to 850 vehicles an hour at peak rush hour would contribute to the congestion. Approximately 130 to 160 people would be employed annually during monitoring and about 460 to 600 would be employed annually during closure. The number of vehicles associated with these levels of employment, about 70 at most, would contribute negligibly to congestion.

Table J-66 lists the impacts associated with the delivery of fabricated disposal container components from a manufacturing site to the repository. A total of 11,300 containers (17,000 under the derated waste package scenario) would be delivered; if a rail line to Yucca Mountain was not available, the mode of transportation would be a combination of rail and overweight truck. The analysis assumes that the capacity of each railcar would be two containers and that the capacity of a truck would be one container, so there would be 5,650 railcar shipments to Nevada and 11,300 truck shipments to the Yucca Mountain site (8,400 rail shipments and 17,000 truck shipments if derated waste packages were used). The analysis estimated impacts for one national rail route representing a potential route from a manufacturing facility to a Nevada rail siding. The analysis estimated the impacts of transporting the containers from this siding over a single truck route—the Apex/Dry Lake route analyzed for the transportation of spent nuclear fuel and high-level radioactive waste by heavy-haul trucks. Although the actual mileage from a manufacturing facility could be shorter, DOE decided to select a distance that represents a conservative

Table J-66. Impacts of disposal container shipments for 24 years of the Proposed Action.[a]

Type of shipment	Number of shipments	Vehicle emissions-related health effects	Traffic fatalities
Rail and truck	5,650 - 8,400 rail/ 11,300 - 17,000 truck	0.088 - 0.13	2.2 - 3.2

a. Impacts of transporting drip shields and emplacement pallets are included in results listed in Table J-64.

estimate [4,439 kilometers (2,758 miles)]. The impacts are split into two subcategories—health effects from vehicle emissions and fatalities from transportation accidents.

Air Quality

The exhaust from vehicles involved in the transport of personnel and materials to the repository would emit carbon monoxide, nitrogen dioxide, sulfur dioxide, and particulate matter (PM_{10}). Because carbon monoxide is the principal pollutant of interest for evaluating impacts caused by motor vehicle emissions, the analysis focused on it. Table J-67 indicates the basis for selecting carbon monoxide as the principal pollutant of concern.

Table J-67. Listed pollutants and pollutant of interest.

Listed pollutant	Gasoline emissions	Diesel emissions
Carbon monoxide	Total emissions into the basin are larger than for diesel	More per vehicle-mile, but total emissions are less
Sulfur dioxide	Very minor problem with modern gasoline	Emits slightly more than gasoline
Nitrogen oxides	Limit less restrictive than carbon monoxide limit	
Particulate matter	Dust,[b] asphalt, and combustion particles	
Ozone	Limit less restrictive than carbon monoxide limit[c]	
Lead	Not a problem with modern gasoline	Does not produce lead

a. Source: 40 CFR 93.153.
b. Of most concern from earthmoving rather than fuel emissions (see DIRS 155557-Clark County 2001, all).
c. Ozone is not an emission but a product of sunlight acting on hydrocarbons and nitrogen oxides.

The analysis assumed that most of the personnel who would commute to the repository would reside in the Las Vegas area and that most of the materials would travel to the repository from the Las Vegas area. To estimate maximum potential emissions to the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide (DIRS 101826-FHWA 1996, pp. 3-53 and 3-54), the analysis assumed that all personnel and material would travel from the center of Las Vegas to the repository. Table J-68 lists the estimated annual amount of carbon monoxide that would be emitted to the valley airshed during the phases of the repository project and the percent of the corresponding threshold level. Although it can be a health hazard (see Table J-65), its emission rate in the Las Vegas basin would be below the standard.

Table J-68. Annual range of carbon monoxide emitted to Las Vegas Valley airshed from transport of personnel and material to repository (kilograms per year)[a] for all modes of the Proposed Action.

Phase	Annual emission rate	Percent of GCR threshold level[b]
Construction	41,000 - 45,000	45 - 50
Emplacement and development	44,000 - 62,000	49 - 69
Operations and monitoring period	6,400 - 8,200	7 - 9
Closure	33,000 - 39,000	36 - 43

a. To convert kilograms to tons, multiply by 0.0011023.
b. GCR = General Conformity Rule; the emission threshold level for carbon monoxide in a nonattainment area is 91,000 kilograms (100 tons) per year (40 CFR 93.153).

As listed in Table J-68, the annual amount of carbon monoxide emitted to the nonattainment area would be below the threshold level during all phases of the Proposed Action. In the operation phase, the estimated annual amount of carbon monoxide emitted would be greatest (49 to 69 percent) to the threshold level. Relative to the vehicle emissions from the repository-bound high-level radioactive waste and spent nuclear fuel, the emissions from the transport of personnel and materials is substantially greater for all transportation implementing alternatives.

DOE conducted a conformity review using the guidance in DIRS 155566-DOE (2000, all) to estimate carbon monoxide emissions from the transportation of personnel, materials, and supplies through the Las Vegas air basin under each transportation implementing alternative. The transportation of personnel, materials, and supplies would be the main repository-related contributor of carbon monoxide to the nonattainment area. Compared to the total from all sources in the nonattainment area, the transportation of personnel, materials, and supplies to Yucca Mountain would add, at most, an additional 0.07 percent to the 2000 daily levels of carbon monoxide in the air basin (DIRS 156706-Clark County 2000, Appendix A, Table 1-3).

For areas that are in attainment, pollutant concentrations in the ambient air probably would increase due to the additional traffic but, given the relatively small amount of traffic that passes through these areas, the additional traffic would be unlikely to cause the ambient air quality standards to be exceeded.

Noise

Traffic-related noise on major transportation routes used by the workforce would likely increase. The analysis of impacts from traffic noise assumed that the workforce would come from Nye County (20 percent) and Clark County (80 percent). During the period of maximum employment in 2015, the analysis estimated a daily maximum of 576 vehicles would pass through the Gate 100 entrance at Mercury during rush hour [compared to a baseline of 232 vehicles per hour (DIRS 101811-DOE 1996, pp. 4-43 and 4-45)]. One-hour equivalent rush hour noise levels resulting from increased traffic would increase by 3.4 dBA at Indian Springs and 4.4 dBA at Mercury over background noise levels of 66.6 and 65.5 dBA, respectively. The increase could be perceptible to the community but, because of its short duration and existing highway noise, would be unlikely to result in an adverse public response.

J.3.6.2 Impacts of Transporting Wastes from the Repository

During repository construction and operations, DOE would ship waste and sample material from the repository. The waste would include hazardous, mixed, and low-level radioactive waste. Samples would include radioactive and nonradioactive hazardous materials shipped to laboratories for analysis. In addition, nonhazardous solid waste could be shipped from the repository site to the Nevada Test Site for disposal. However, as noted in Chapter 2, DOE proposes to include an industrial landfill on the repository site. Table J-69 summarizes the health impacts from wastes that DOE would ship from the repository.

Table J-69. Health impacts and fuel consumption from transportation of waste from the Yucca Mountain repository.

Phase	Kilometers[a] traveled (in millions)	Traffic fatalities	Fuel consumption (millions of liters)[b]	Vehicle emissions-related fatalities
Construction	0.37 - 0.39	0.0061 - 0.0066	0.086 - 0.092	0.00077 - 0.0082
Emplacement and development (24 years)	2.8 - 3.1	0.047 - 0.051	0.67 - 0.72	0.0040 - 0.0043
Monitoring (76 to 300 years)	1.8 - 6.2	0.031 - 0.10	0.44 - 1.5	0.0026 - 0.0088
Closure	0.67 - 0.88	0.011 - 0.020	0.16 - 0.24	0.0014 - 0.0025
Totals[c]	6.1 - 11	0.10 - 0.18	1.4 - 2.5	0.0093 - 0.016

a. To convert kilometers to miles, multiply by 0.62137.
b. To convert liters to gallons, multiply by 0.26418.
c. Totals might not equal sums due to rounding.

Occupational and Public Health and Safety

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small and would present little risk to public health and safety. This waste could be shipped by rail (if DOE built a rail line to the repository site) or by legal-weight truck to permitted disposal facilities. The principal risks associated with shipments of these materials would be related to traffic accidents. These risks would include 0.01 fatality for the combined construction, operation and monitoring, and closure phases for hazardous wastes.

DOE probably would ship low-level radioactive waste by truck to existing disposal facilities on the Nevada Test Site. Although these shipments would not use public highways, DOE estimated their risks. As with shipments of hazardous waste, the principal risk in transporting low-level radioactive waste would be related to traffic accidents. Because traffic on the Nevada Test Site is regulated by the Nye County Sheriff's Department, DOE assumed that accident rates on the site are similar to those of secondary highways in Nevada. Low-level radioactive waste would not be present during the construction of the repository. Therefore, accidents involving such waste could occur only during the operation and monitoring and the closure phases, although most of this waste would be generated during the construction and operation and monitoring phases. DOE estimates between 0.0038 and 0.0053 traffic fatality from the transportation of low-level radioactive waste during the repository construction, operation and monitoring, and closure phases. Table J-69 lists the impacts of transporting wastes, including hazardous waste, sanitary waste, construction debris, and low-level radioactive waste.

Air Quality

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small. Vehicle emissions due to these shipments would present little risk to public health and safety.

Biological Resources and Soils

The transportation of people, materials, and wastes during the construction, operation and monitoring, and closure phases of the repository could involve between 610 and 1,100 million vehicle-kilometers (between 380 and 680 million vehicle-miles) of travel on highways in southern Nevada depending on the repository operating mode. This travel would use existing highways that pass through desert tortoise habitat. Individual desert tortoises probably would be killed. However, because populations of the species are low in the vicinity of the routes (DIRS 103160-Bury and Germano 1994, pp. 57 to 72), few would be lost. Thus, the loss of individual desert tortoises due to repository traffic would not be likely to be a threat to the conservation of this species. In accordance with requirements of Section 7 of the Endangered Species Act (16 U.S.C. 1531 *et seq.*), DOE would consult with the Fish and Wildlife Service and would comply with mitigation measures resulting from that consultation to limit losses of desert tortoises from repository traffic.

J.3.6.3 Impacts from Transporting Other Materials and People in Nevada for Inventory Modules 1 and 2

The analysis evaluated impacts to occupational and public health and safety in Nevada from the transport of materials, wastes, and workers (including repository-related commuter travel) for construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of materials in Inventory Modules 1 and 2. The analysis assumed that the routes and transportation characteristics (for example, accident rates) for transportation associated with the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of trips for materials, wastes, and workers traveling to the repository.

Table J-70 lists estimated incident-free (vehicle emissions) impacts and traffic (accident) fatality impacts in Nevada for the transportation of materials, wastes, and workers (including repository-related commuter travel) for the construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of the materials in Inventory Modules 1 and 2. The range includes all lower-temperature repository operating mode scenarios.

Table J-70. Health impacts from transportation of materials, consumables, personnel, and waste for Modules 1 and 2.[a]

Phase	Kilometers traveled (millions)[b]	Traffic fatalities	Emission-related health effects
Construction	61 - 67	0.67 - 0.74	0.086 - 0.096
Emplacement and Development	510 - 640	8.5 - 9.8	0.78 - 0.92
Operation and Monitoring	150 - 480	1.9 - 6.1	0.24 - 0.79
Closure	59 - 97	0.65 - 1.0	0.084 - 0.13
Totals	***820 - 1,200***	***12 - 18***	***1.2 - 1.9***

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.
c. Totals might not equal sums due to rounding.

Even with the increased transportation of the other materials included in Module 1 or 2, DOE expects that the transportation of materials, consumables, personnel, and waste to and from the repository would be minor contributors to all transportation on a local, state, and national level. Public and worker health impacts would be small from transportation accidents involving nonradioactive hazardous materials. On average, in the United States there is about 1 fatality caused by the hazardous material being transported for each 30 million shipments by all modes (DIRS 103717-DOT 1998, p. 1; DIRS 103720-DOT Undated, Exhibit 2b).

J.4 State-Specific Impacts and Route Maps

This section contains maps and tables that illustrate the estimated impacts to 45 states and the District of Columbia (Alaska and Hawaii are not included; estimated impacts in Montana, North Dakota, and Rhode Island would be zero). As discussed previously in this appendix, DOE used state- and route-specific data to estimate transportation impacts. At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Therefore, the transportation routes discussed in this section might not be the exact routes actually used for shipments to Yucca Mountain. Nevertheless, because the analysis is based primarily on the existing Interstate Highway System and rail rolling stock, the analysis presents a representative estimate of what the actual transportation impacts would likely be.

In addition, under the national mostly rail transportation scenario, potential impacts in each state vary according to the ending node in Nevada. There are six different points of transfer from national to Nevada transportation (Caliente, Dry Lake, Jean, Beowawe, Eccles, and Apex). The routes used in the national analysis depend on the transfer point through which the shipments would pass. Tables J-71 through J-92 list the transportation impacts for 47 of the states and the District of Colombia, and Figures J-31 through J-52 are maps of the routes analyzed for each region.

In Nevada, the impacts vary according to the rail or heavy-haul implementing alternative. Figure J-53 shows the potential routes in the State of Nevada, and Table J-93 lists the impacts in Nevada for each of the eight implementing alternatives.

Table J-70 lists estimated incident-free (vehicle emissions) impacts and traffic (accident) fatality impacts in Nevada for the transportation of materials, wastes, and workers (including repository-related commuter travel) for the construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of the materials in Inventory Modules 1 and 2. The range includes all lower-temperature repository operating mode scenarios.

Table J-70. Health impacts from transportation of materials, consumables, personnel, and waste for Modules 1 and 2.[a]

Phase	Kilometers traveled (millions)[b]	Traffic fatalities	Emission-related health effects
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Totals	***820 - 1,200***	***12 - 18***	***1.2 - 1.9***

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.
c. Totals might not equal sums due to rounding.

Even with the increased transportation of the other materials included in Module 1 or 2, DOE expects that the transportation of materials, consumables, personnel, and waste to and from the repository would be minor contributors to all transportation on a local, state, and national level. Public and worker health impacts would be small from transportation accidents involving nonradioactive hazardous materials. On average, in the United States there is about 1 fatality caused by the hazardous material being transported for each 30 million shipments by all modes (DIRS 103717-DOT 1998, p. 1; DIRS 103720-DOT Undated, Exhibit 2b).

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In Nevada, the impacts vary according to the rail or heavy-haul implementing alternative. Figure J-53 shows the potential routes in the State of Nevada, and Table J-93 lists the impacts in Nevada for each of the eight implementing alternatives.

Table J-71. Estimated transportation impacts for the States of Alabama and Georgia.

State and impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ALABAMA							
Shipments							
Truck (originating/total)	1,755/1,755	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	283/2,413	283/2,413	283/2,413	283/2,413	283/2,413	283/2,413
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$5.0\times10^{0}/2.5\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$4.9\times10^{0}/2.4\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$	$3.7\times10^{1}/1.8\times10^{-3}$
Workers (person-rem/LCFs)	$4.2\times10^{1}/1.7\times10^{-2}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.2\times10^{1}/8.8\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$	$2.1\times10^{1}/8.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.6\times10^{-4}/2.3\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$7.0\times10^{-4}/3.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$	$3.1\times10^{-4}/1.5\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.0×10^{-3}	8.4×10^{-4}	8.4×10^{-4}	1.4×10^{-3}	8.4×10^{-4}	8.4×10^{-4}	8.4×10^{-4}
Fatalities	0.003	0.009	0.009	0.011	0.009	0.009	0.009
GEORGIA							
Shipments							
Truck (originating/total)	1,664/13,169	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	321/2,561	321/2,561	321/2,359	321/2,561	321/2,561	321/2,561
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.2\times10^{2}/1.1\times10^{-1}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$9.4\times10^{1}/4.7\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$	$1.0\times10^{2}/5.0\times10^{-2}$
Workers (person-rem/LCFs)	$4.0\times10^{2}/1.6\times10^{-1}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.1\times10^{2}/4.4\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$	$1.2\times10^{2}/4.8\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$5.6\times10^{-2}/2.8\times10^{-5}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.2\times10^{-2}/6.1\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$	$1.4\times10^{-2}/7.2\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.4×10^{-2}	4.8×10^{-2}	4.8×10^{-2}	4.8×10^{-2}
Fatalities	0.22	0.10	0.10	0.09	0.10	0.10	0.10

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

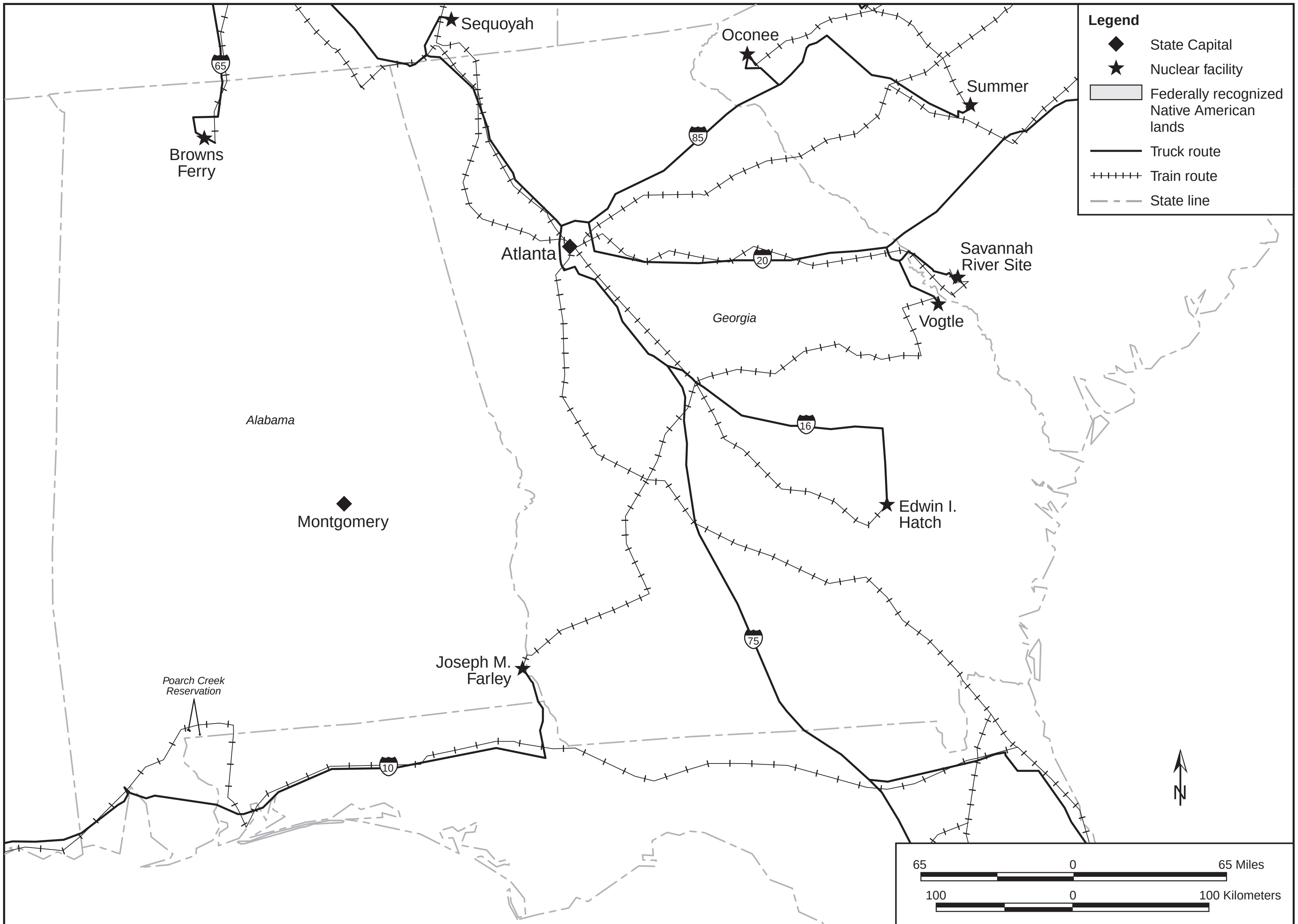
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-31. Highway and rail routes used to analyze transportation impacts - Alabama and Georgia.

Table J-72. Estimated transportation impacts for the State of Arkansas.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ARKANSAS							
Shipments							
Truck (originating/total)	794/794	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	121/201	121/201	121/121	121/258	121/201	121/201
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.3\times10^{0}/1.1\times10^{-3}$	$1.1\times10^{0}/5.4\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$	$9.5\times10^{-1}/4.8\times10^{-4}$	$1.2\times10^{0}/5.8\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$	$1.1\times10^{0}/5.4\times10^{-4}$
Workers (person-rem/LCFs)	$2.1\times10^{1}/8.3\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$8.7\times10^{0}/3.5\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$	$7.8\times10^{0}/3.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.6\times10^{-5}/2.3\times10^{-8}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$2.4\times10^{-4}/1.2\times10^{-7}$	$4.7\times10^{-4}/2.4\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$	$3.8\times10^{-4}/1.9\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.9×10^{-4}	2.0×10^{-4}	2.0×10^{-4}	1.3×10^{-4}	2.4×10^{-4}	2.0×10^{-4}	2.0×10^{-4}
Fatalities	1.2×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	1.6×10^{-3}	5.3×10^{-3}	3.7×10^{-3}	3.7×10^{-3}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

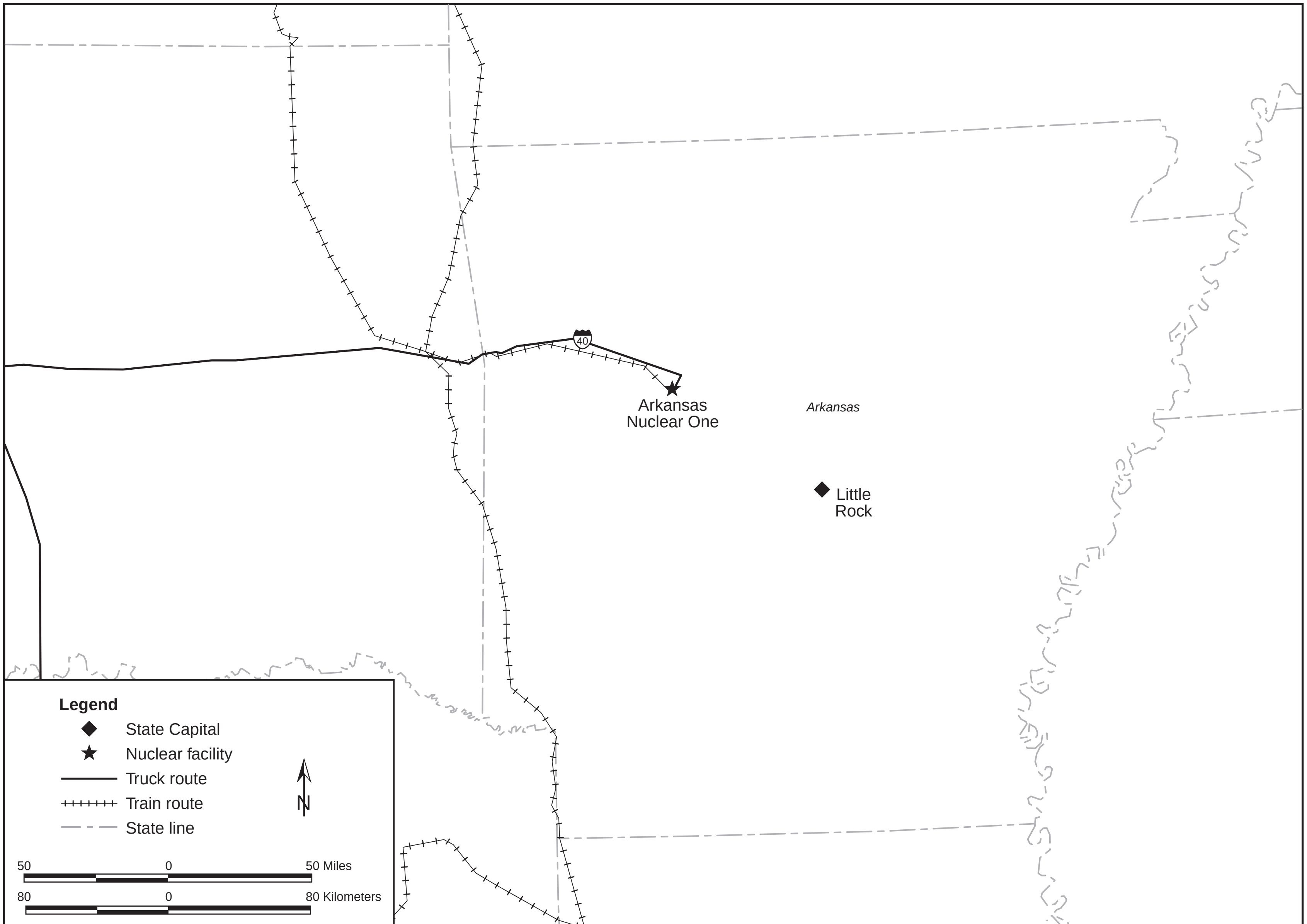
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-32. Highway and rail routes used to analyze transportation impacts - Arkansas.

Table J-73. Estimated transportation impacts for the States of Arizona and New Mexico.

		Mostly rail					
		Ending rail node in Nevada[a]					
Impact category	Mostly legal-weight truck	Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ARIZONA							
Shipments							
Truck (originating/total)	1,118/51,036	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	193/374	193/431	193/1,145	193/193	193/308	193/585
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$9.2\times10^{1}/4.6\times10^{-2}$	$5.5\times10^{0}/2.7\times10^{-3}$	$6.1\times10^{0}/3.1\times10^{-3}$	$1.3\times10^{1}/6.7\times10^{-3}$	$3.4\times10^{0}/1.7\times10^{-3}$	$4.7\times10^{0}/2.3\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$
Workers (person-rem/LCFs)	$3.2\times10^{2}/1.3\times10^{-1}$	$2.3\times10^{1}/9.0\times10^{-3}$	$2.5\times10^{1}/1.0\times10^{-2}$	$5.5\times10^{1}/2.2\times10^{-2}$	$1.5\times10^{1}/6.0\times10^{-3}$	$2.0\times10^{1}/7.9\times10^{-3}$	$3.1\times10^{1}/1.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.2\times10^{-3}/6.1\times10^{-7}$	$3.6\times10^{-4}/1.8\times10^{-7}$	$4.7\times10^{-4}/2.3\times10^{-7}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$3.8\times10^{-5}/1.9\times10^{-8}$	$2.3\times10^{-4}/1.2\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.2×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	5.1×10^{-3}	1.1×10^{-4}	7.8×10^{-4}	2.4×10^{-3}
Fatalities	8.9×10^{-2}	7.8×10^{-3}	9.4×10^{-3}	2.9×10^{-2}	2.8×10^{-3}	6.0×10^{-3}	1.4×10^{-2}
NEW MEXICO							
Shipments							
Truck (originating/total)	0/3,999	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/181	0/238	0/952	0/154	0/115	0/392
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$5.5\times10^{1}/2.8\times10^{-2}$	$3.4\times10^{-1}/1.7\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$2.3\times10^{0}/1.2\times10^{-3}$	$9.2\times10^{-3}/4.6\times10^{-6}$	$2.1\times10^{-1}/1.1\times10^{-4}$	$7.3\times10^{-1}/3.6\times10^{-4}$
Workers (person-rem/LCFs)	$1.4\times10^{2}/5.8\times10^{-2}$	$3.1\times10^{0}/1.2\times10^{-3}$	$4.0\times10^{0}/1.6\times10^{-3}$	$2.3\times10^{1}/9.3\times10^{-3}$	$1.3\times10^{0}/5.2\times10^{-4}$	$1.9\times10^{0}/7.8\times10^{-4}$	$6.6\times10^{0}/2.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.6\times10^{-3}/8.2\times10^{-7}$	$3.9\times10^{-5}/2.0\times10^{-8}$	$5.3\times10^{-5}/2.7\times10^{-8}$	$3.0\times10^{-4}/1.5\times10^{-7}$	$1.2\times10^{-6}/6.1\times10^{-10}$	$2.4\times10^{-5}/1.2\times10^{-8}$	$7.9\times10^{-5}/3.9\times10^{-8}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.0×10^{-2}	1.9×10^{-4}	2.4×10^{-4}	1.3×10^{-3}	4.3×10^{-6}	1.2×10^{-4}	4.0×10^{-4}
Fatalities	0.053	0.001	0.002	0.010	0.001	0.001	0.003

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

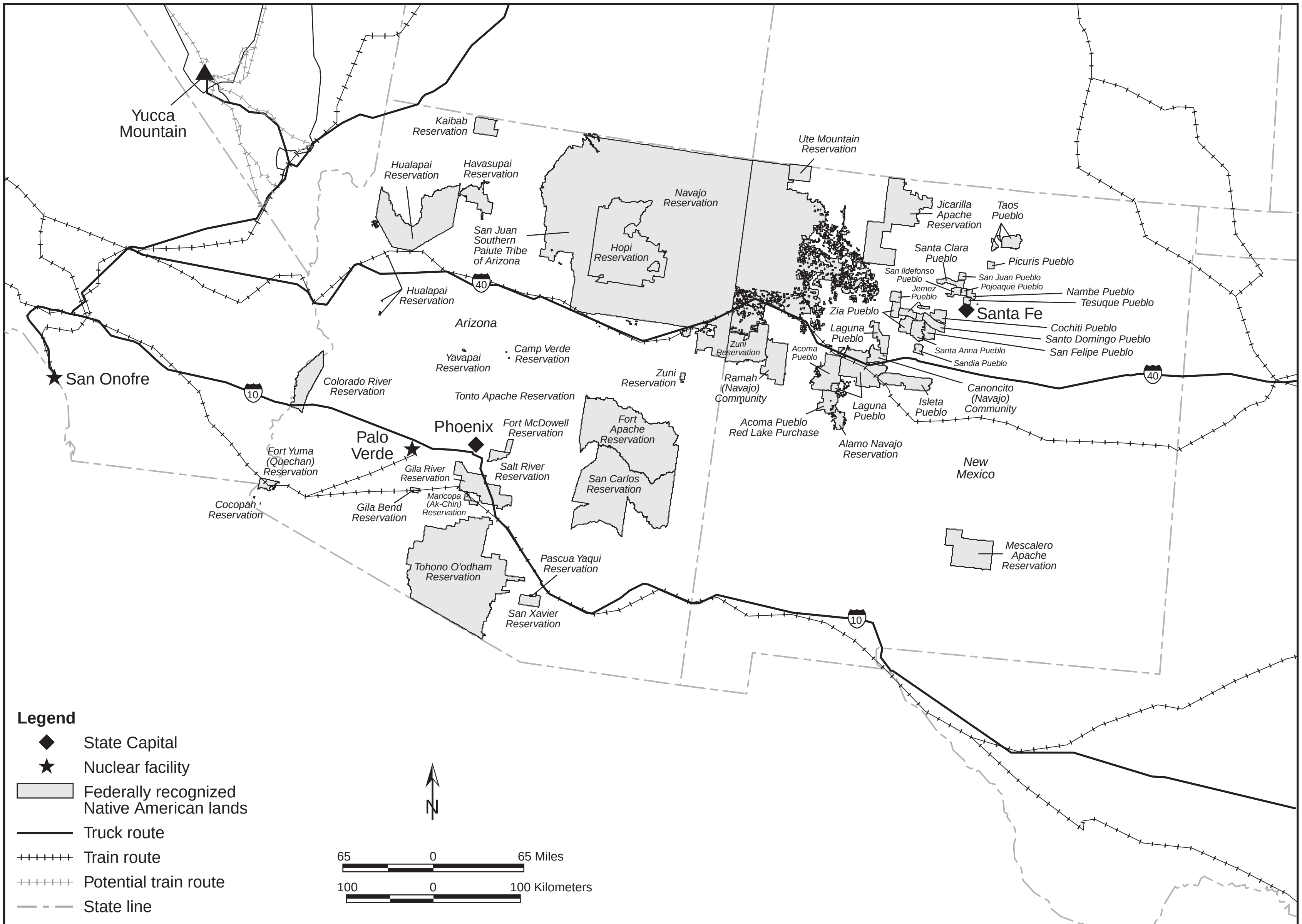


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Figure J-33. Highway and rail routes used to analyze transportation impacts - Arizona and New Mexico.

Table J-74. Estimated transportation impacts for the State of California.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
CALIFORNIA							
Shipments							
Truck (originating/total)	1,750/6,867	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	286/660	286/750	286/1,464	286/512	286/594	286/904
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.3\times10^{2}/6.3\times10^{-2}$	$4.8\times10^{1}/2.4\times10^{-2}$	$5.3\times10^{1}/2.6\times10^{-2}$	$6.6\times10^{1}/3.3\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$4.6\times10^{1}/2.3\times10^{-2}$	$5.7\times10^{1}/2.9\times10^{-2}$
Workers (person-rem/LCFs)	$2.7\times10^{2}/1.1\times10^{-1}$	$4.5\times10^{1}/1.8\times10^{-2}$	$5.0\times10^{1}/2.0\times10^{-2}$	$7.7\times10^{1}/3.1\times10^{-2}$	$5.2\times10^{1}/2.1\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$5.7\times10^{1}/2.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$9.7\times10^{-3}/4.9\times10^{-6}$	$2.2\times10^{-2}/1.1\times10^{-5}$	$2.5\times10^{-2}/1.3\times10^{-5}$	$3.2\times10^{-2}/1.6\times10^{-5}$	$3.4\times10^{-2}/1.7\times10^{-5}$	$2.1\times10^{-2}/1.1\times10^{-5}$	$2.7\times10^{-2}/1.3\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.3×10^{-2}	2.1×10^{-2}	2.3×10^{-2}	3.0×10^{-2}	3.1×10^{-2}	2.0×10^{-2}	2.5×10^{-2}
Fatalities	0.052	0.061	0.073	0.131	0.073	0.055	0.087

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

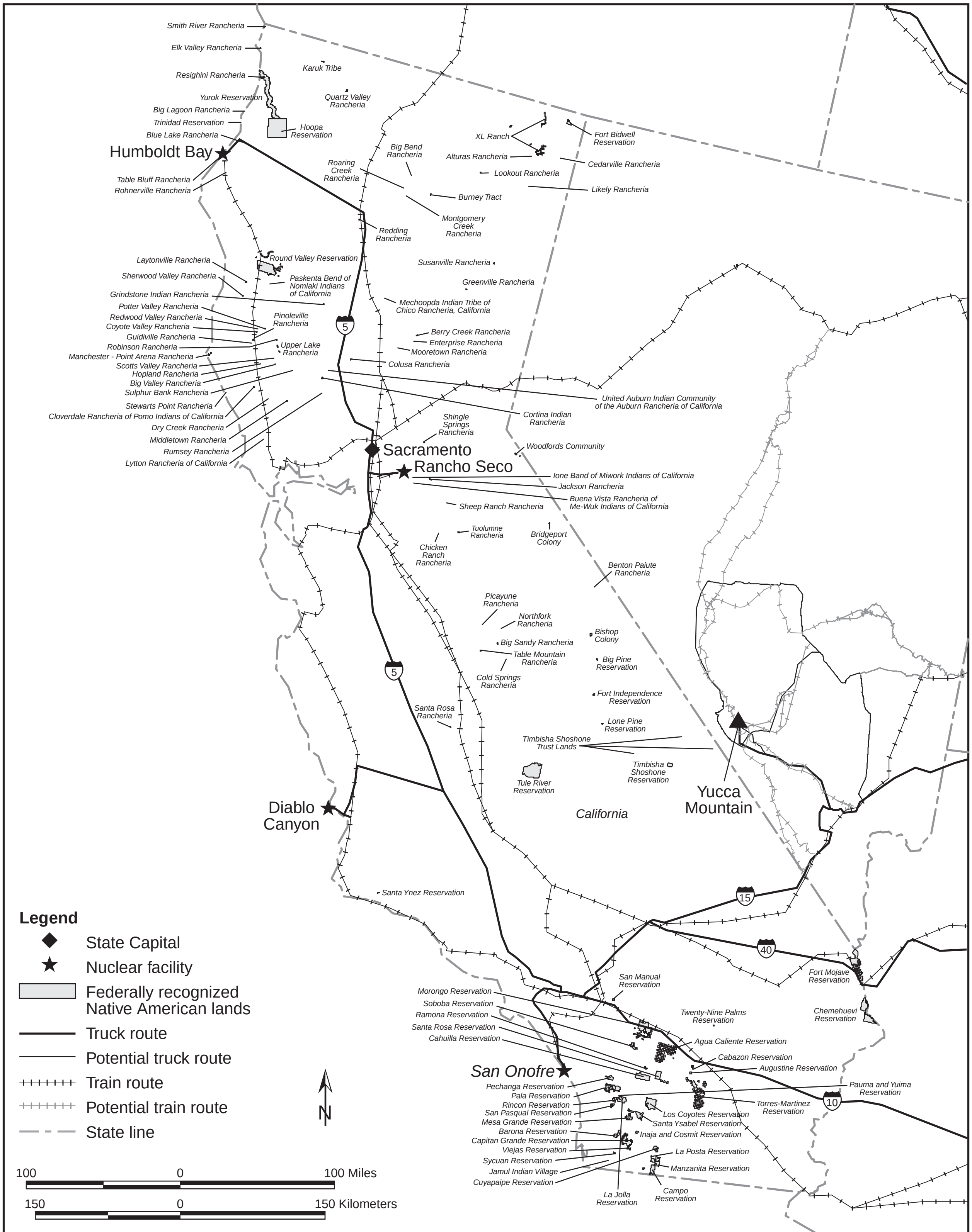
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-34. Highway and rail routes used to analyze transportation impacts - California.

Table J-75. Estimated transportation impacts for the States of Colorado, Kansas, and Nebraska (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
COLORADO							
Shipments							
Truck (originating/total)	312/708	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	36/7,904	36/7,847	36/7,133	36/8,085	36/7,970	36/7,693
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.4\times10^{0}/2.2\times10^{-3}$	$1.6\times10^{1}/8.2\times10^{-3}$	$1.4\times10^{1}/7.1\times10^{-3}$	$3.2\times10^{0}/1.6\times10^{-3}$	$2.0\times10^{1}/1.0\times10^{-2}$	$1.9\times10^{1}/9.4\times10^{-3}$	$8.5\times10^{0}/4.3\times10^{-3}$
Workers (person-rem/LCFs)	$1.8\times10^{1}/7.4\times10^{-3}$	$4.0\times10^{1}/1.6\times10^{-2}$	$3.7\times10^{1}/1.5\times10^{-2}$	$1.2\times10^{1}/4.9\times10^{-3}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.5\times10^{1}/1.8\times10^{-2}$	$2.7\times10^{1}/1.1\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$3.4\times10^{-4}/1.7\times10^{-7}$	$5.2\times10^{-3}/2.6\times10^{-6}$	$4.4\times10^{-3}/2.2\times10^{-6}$	$7.9\times10^{-4}/3.9\times10^{-7}$	$6.6\times10^{-3}/3.3\times10^{-6}$	$6.1\times10^{-3}/3.1\times10^{-6}$	$3.0\times10^{-3}/1.5\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.9×10^{-4}	8.0×10^{-3}	6.9×10^{-3}	1.4×10^{-3}	9.9×10^{-3}	9.2×10^{-3}	4.0×10^{-3}
Fatalities	0.005	0.024	0.021	0.007	0.028	0.026	0.015
KANSAS							
Shipments							
Truck (originating/total)	396/396	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	63/4,253	63/4,253	63/4,249	63/4,310	63/4,253	63/4,253
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.0\times10^{0}/3.0\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.8\times10^{1}/9.2\times10^{-3}$	$1.7\times10^{1}/8.5\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$	$1.7\times10^{1}/8.4\times10^{-3}$
Workers (person-rem/LCFs)	$2.6\times10^{1}/1.0\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.6\times10^{1}/3.5\times10^{-2}$	$8.4\times10^{1}/3.4\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$	$8.3\times10^{1}/3.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$2.4\times10^{-4}/1.2\times10^{-7}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$8.7\times10^{-3}/4.3\times10^{-6}$	$8.0\times10^{-3}/4.0\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$	$7.9\times10^{-3}/3.9\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.6×10^{-4}	8.5×10^{-3}	8.5×10^{-3}	9.3×10^{-3}	8.6×10^{-3}	8.5×10^{-3}	8.5×10^{-3}
Fatalities	0.003	0.049	0.049	0.051	0.050	0.049	0.049
NEBRASKA							
Shipments							
Truck (originating/total)	532/40,799	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	103/7,657	103/7,657	103/7,097	103/7,714	103/7,657	103/7,657
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.4\times10^{2}/3.2\times10^{-1}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$5.9\times10^{1}/2.9\times10^{-2}$	$6.3\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$
Workers (person-rem/LCFs)	$2.0\times10^{3}/7.8\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.7\times10^{2}/1.5\times10^{-1}$	$4.0\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$	$3.9\times10^{2}/1.6\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$3.0\times10^{-2}/1.5\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.6\times10^{-2}/1.8\times10^{-5}$	$4.0\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$	$3.9\times10^{-2}/2.0\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	5.7×10^{-2}	2.4×10^{-2}	2.4×10^{-2}	2.3×10^{-2}	2.4×10^{-2}	2.4×10^{-2}	2.4×10^{-2}
Fatalities	0.83	0.18	0.18	0.17	0.18	0.18	0.18

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-75. Estimated transportation impacts for the States of Colorado, Kansas, and Nebraska (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

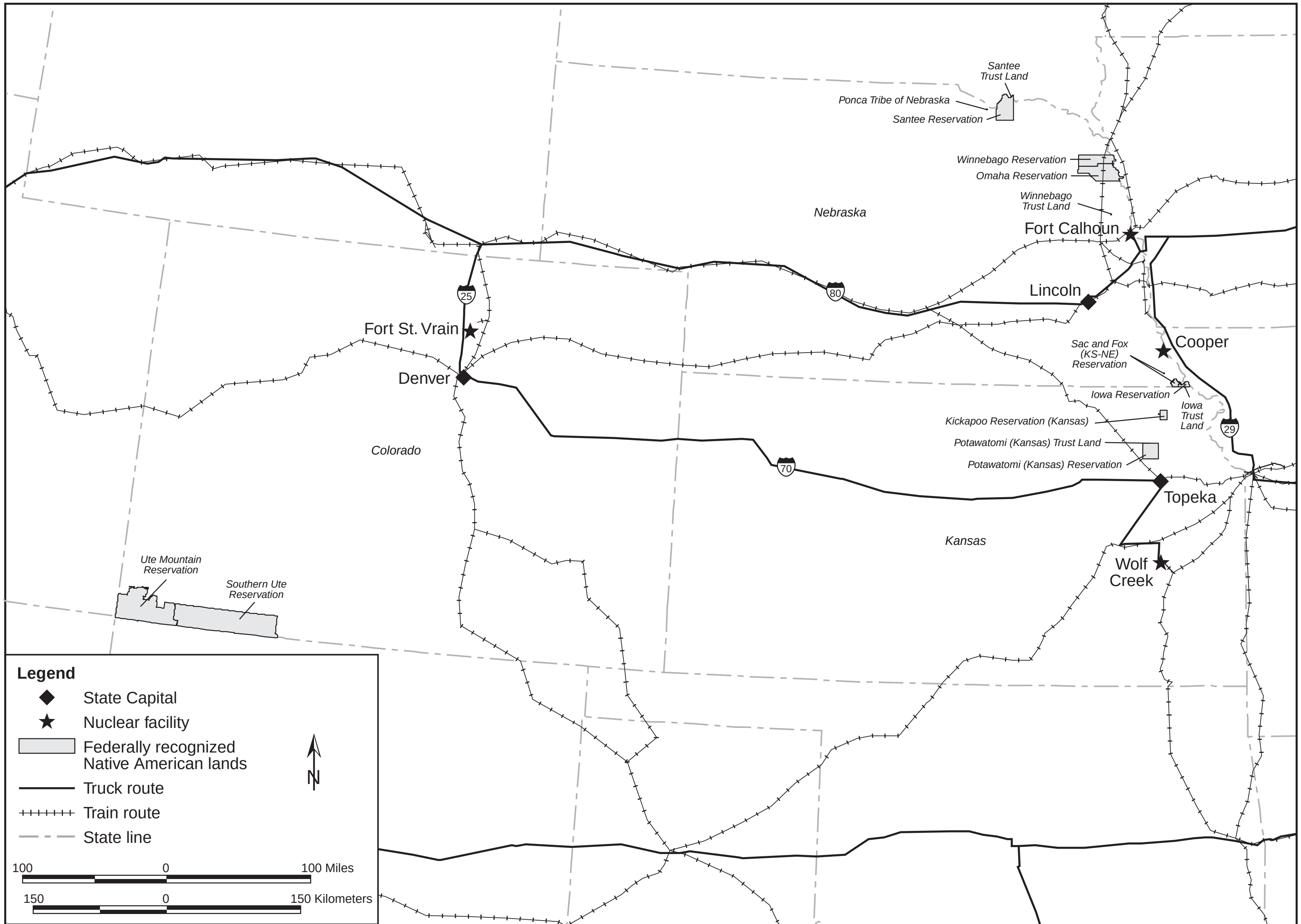
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-35. Highway and rail routes used to analyze transportation impacts - Colorado, Kansas, and Nebraska.

Table J-76. Estimated transportation impacts for the States of Connecticut, Rhode Island, and New York (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
CONNECTICUT							
Shipments							
Truck (originating/total)	1,247/1,247	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	295/295	295/295	295/295	295/295	295/295	295/295
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.5\times10^{1}/7.5\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$	$9.1\times10^{0}/4.6\times10^{-3}$
Workers (person-rem/LCFs)	$3.4\times10^{1}/1.4\times10^{-2}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$	$1.7\times10^{1}/7.0\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$8.2\times10^{-3}/4.1\times10^{-6}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$	$1.6\times10^{-1}/8.2\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.5×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
Fatalities	0.005	0.135	0.135	0.135	0.135	0.135	0.135
RHODE ISLAND							
Shipments	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Incident-free impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Population (person-rem/LCFs)[h]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Population (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Nonradiological impacts	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Vehicle emissions (LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Fatalities	0/0	0/0	0/0	0/0	0/0	0/0	0/0
NEW YORK							
Shipments							
Truck (originating/total)	2,571/5,287	426/580	426/580	426/580	426/580	426/580	426/580
Rail (originating/total)	0/0	350/861	350/861	350/861	350/861	350/861	350/861
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$6.3\times10^{1}/3.2\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$	$3.1\times10^{1}/1.6\times10^{-2}$
Workers (person-rem/LCFs)	$1.6\times10^{2}/6.2\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$	$6.7\times10^{1}/2.7\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$7.0\times10^{-3}/3.5\times10^{-6}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$	$4.9\times10^{-2}/2.4\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}	1.3×10^{-2}
Fatalities	0.042	0.122	0.122	0.122	0.122	0.122	0.122

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-76. Estimated transportation impacts for the States of Connecticut, Rhode Island, and New York (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

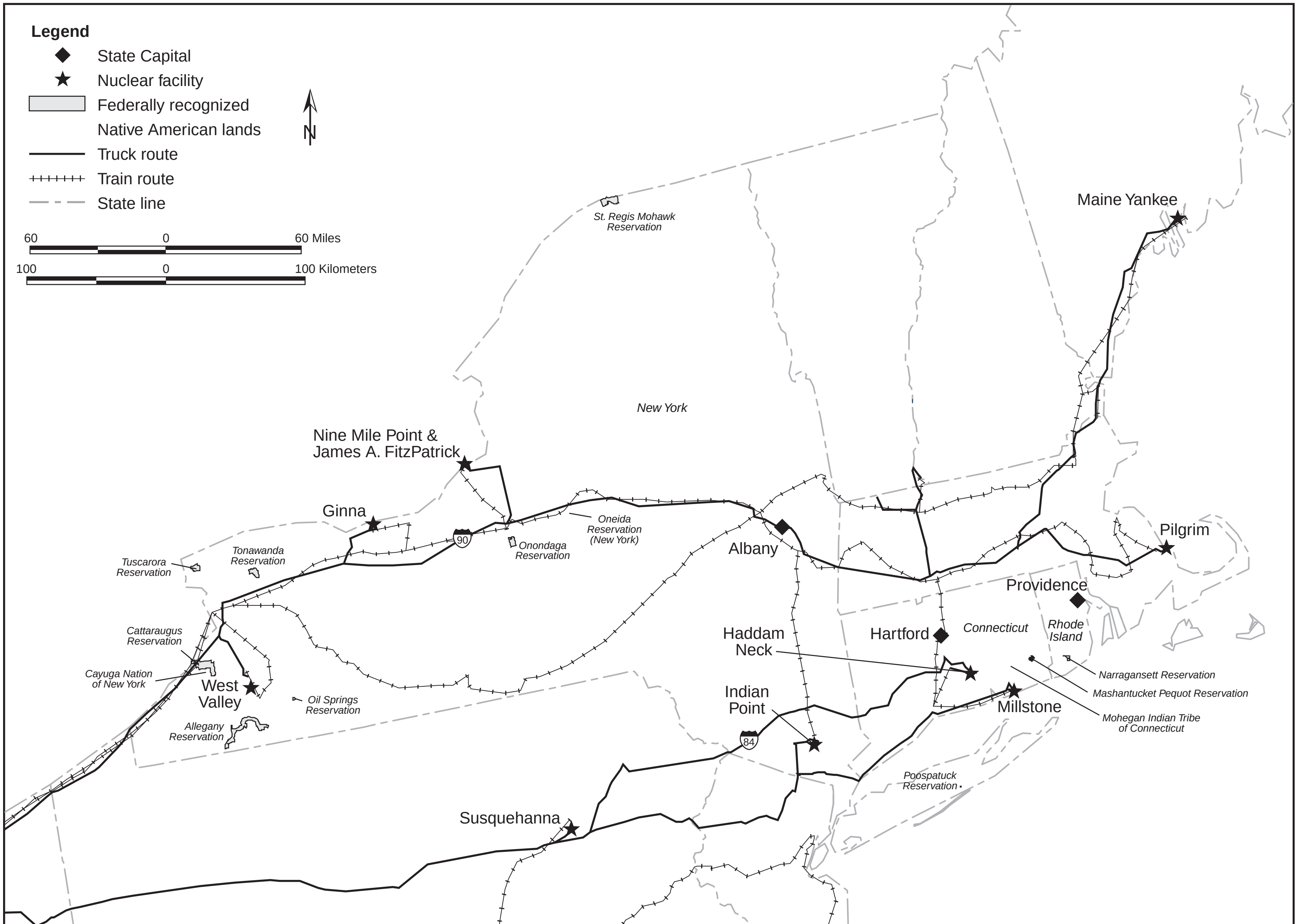
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-36. Highway and rail routes used to analyze transportation impacts - Connecticut, Rhode Island, and New York.

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 1 of 3).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
DELAWARE							
Shipments							
Truck (originating/total)	0/1,077	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.6\times10^{0}/8.2\times10^{-4}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Workers (person-rem/LCFs)	$1.7\times10^{0}/6.9\times10^{-4}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Accident dose risk							
Population (person-rem/LCFs)	$5.2\times10^{-4}/2.6\times10^{-7}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$	$0.0\times10^{0}/0.0\times10^{0}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-4}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
Fatalities	3.1×10^{-4}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}	0.0×10^{0}
MARYLAND							
Shipments							
Truck (originating/total)	867/1,944	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	169/312	169/312	169/312	169/312	169/312	169/312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.5\times10^{1}/1.3\times10^{-2}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$	$1.0\times10^{1}/5.0\times10^{-3}$
Workers (person-rem/LCFs)	$4.8\times10^{1}/1.9\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$	$1.3\times10^{1}/5.1\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$6.6\times10^{-3}/3.3\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$	$3.2\times10^{-3}/1.6\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.4×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}
Fatalities	0.007	0.007	0.007	0.007	0.007	0.007	0.007

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 2 of 3).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
VIRGINIA							
Shipments							
Truck (originating/total)	1,538/3,409	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	340/340	340/340	340/340	340/340	340/340	340/340
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.2\times10^{1}/1.1\times10^{-2}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$	$9.6\times10^{0}/4.8\times10^{-3}$
Workers (person-rem/LCFs)	$8.2\times10^{1}/3.3\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$	$2.6\times10^{1}/1.0\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$2.1\times10^{-3}/1.1\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$	$2.1\times10^{-3}/1.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.4×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}
Fatalities	0.027	0.011	0.011	0.011	0.011	0.011	0.011
WEST VIRGINIA							
Shipments							
Truck (originating/total)	0/3,409	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/509	0/509	0/509	0/509	0/509	0/509
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$3.4\times10^{1}/1.7\times10^{-2}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$	$1.6\times10^{0}/8.1\times10^{-4}$
Workers (person-rem/LCFs)	$6.2\times10^{1}/2.5\times10^{-2}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$	$6.6\times10^{0}/2.6\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.8\times10^{-3}/9.2\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$	$3.9\times10^{-4}/2.0\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.9×10^{-3}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}	8.5×10^{-4}
Fatalities	0.032	0.004	0.004	0.004	0.004	0.004	0.004

Table J-77. Estimated transportation impacts for the States of Delaware, Maryland, Virginia, West Virginia, and the District of Columbia (page 3 of 3).

		Mostly rail					
		Ending rail node in Nevada[a]					
Impact category	Mostly legal-weight truck	Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
DISTRICT OF COLUMBIA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/312	0/312	0/312	0/312	0/312	0/312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$0.0\times10^{0}/0.0\times10^{0}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$	$2.7\times10^{0}/1.3\times10^{-3}$
Workers (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$	$5.9\times10^{-1}/2.4\times10^{-4}$
Accident dose risk							
Population (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$	$5.0\times10^{-2}/2.5\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	0.0×10^{0}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}	1.2×10^{-3}
Fatalities	0.0×10^{0}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}	4.8×10^{-3}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

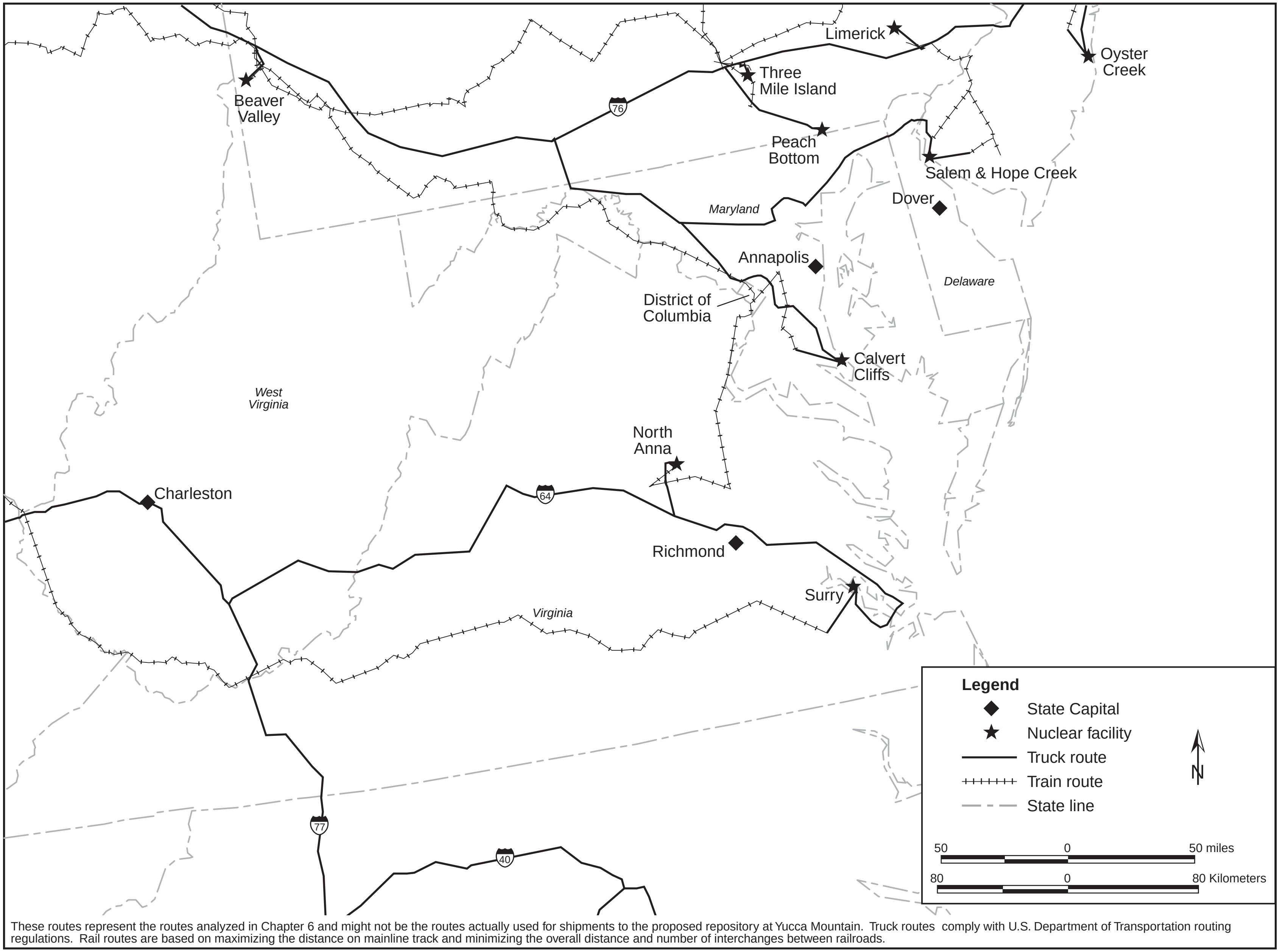


Figure J-37. Highway and rail routes used to analyze transportation impacts - Delaware, Maryland, Virginia, West Virginia, and the District of Columbia.

Table J-78. Estimated transportation impacts for the State of Florida.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
FLORIDA							
Shipments							
Truck (originating/total)	1,666/2,359	491/491	491/491	491/491	491/491	491/491	491/491
Rail (originating/total)	0/0	202/202	202/202	202/202	202/202	202/202	202/202
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.5\times10^{1}/2.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.8\times10^{1}/1.4\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$	$2.3\times10^{1}/1.2\times10^{-2}$
Workers (person-rem/LCFs)	$1.1\times10^{2}/4.3\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$5.0\times10^{1}/2.0\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$	$4.2\times10^{1}/1.7\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.5\times10^{-3}/7.4\times10^{-7}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$9.9\times10^{-3}/5.0\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$	$7.4\times10^{-3}/3.7\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	8.2×10^{-3}	8.2×10^{-3}	1.1×10^{-2}	8.2×10^{-3}	8.2×10^{-3}	8.2×10^{-3}
Fatalities	0.019	0.025	0.025	0.047	0.025	0.025	0.025

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/ Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

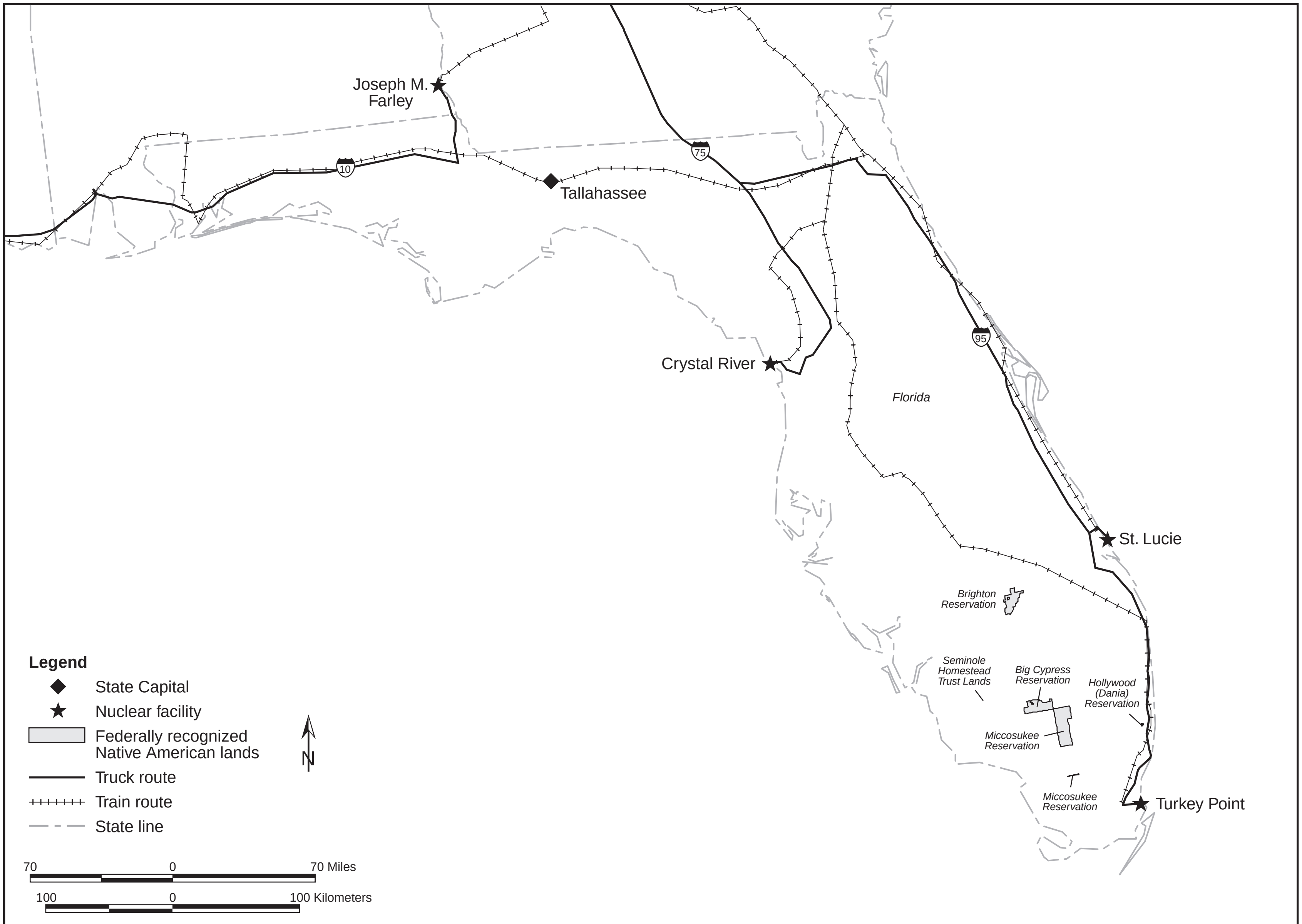
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-38. Highway and rail routes used to analyze transportation impacts - Florida.

Table J-79. Estimated transportation impacts for the State of Iowa.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
IOWA							
Shipments							
Truck (originating/total)	324/40,539	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	57/3,301	57/3,301	57/3,301	57/3,301	57/3,301	57/3,301
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.7\times10^{2}/1.4\times10^{-1}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.0\times10^{1}/3.0\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$	$6.2\times10^{1}/3.1\times10^{-2}$
Workers (person-rem/LCFs)	$8.7\times10^{2}/3.5\times10^{-1}$	$1.4\times10^{2}/5.7\times10^{-2}$	$1.4\times10^{2}/5.7\times10^{-2}$	$1.3\times10^{2}/5.4\times10^{-2}$	$1.4\times10^{2}/5.7\times10^{-2}$	$1.4\times10^{2}/5.7\times10^{-2}$	$1.4\times10^{2}/5.7\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$4.2\times10^{-3}/2.1\times10^{-6}$	$5.8\times10^{-2}/2.9\times10^{-5}$	$5.8\times10^{-2}/2.9\times10^{-5}$	$5.4\times10^{-2}/2.7\times10^{-5}$	$5.8\times10^{-2}/2.9\times10^{-5}$	$5.8\times10^{-2}/2.9\times10^{-5}$	$5.8\times10^{-2}/2.9\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.6×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.7×10^{-2}
Fatalities	0.25	0.09	0.09	0.09	0.09	0.09	0.09

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

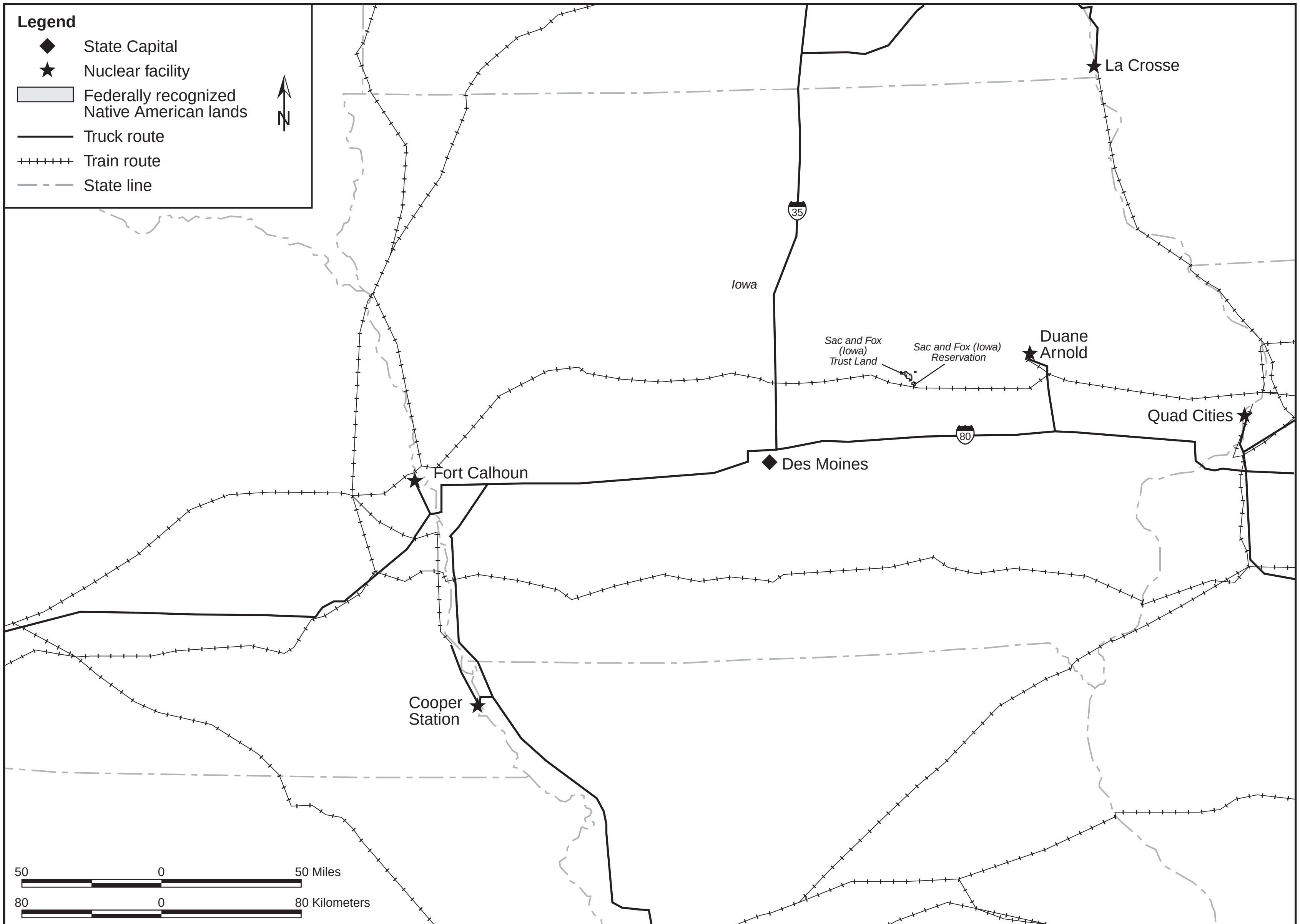
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-39. Highway and rail routes used to analyze transportation impacts - Iowa.

Table J-80. Estimated transportation impacts for the States of Idaho, Oregon, and Washington (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
IDAHO							
Shipments							
Truck (originating/total)	1,088/4,412	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	300/300	433/1,082	433/1,049	433/1,049	433/1,049	433/1,082	433/1,049
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.2\times10^{1}/2.1\times10^{-2}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$	$4.8\times10^{1}/2.4\times10^{-2}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$	$1.4\times10^{1}/7.0\times10^{-3}$
Workers (person-rem/LCFs)	$1.4\times10^{2}/5.5\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$1.7\times10^{2}/6.8\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.7\times10^{-3}/8.7\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$2.4\times10^{-3}/1.2\times10^{-6}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$	$7.9\times10^{-4}/4.0\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	5.2×10^{-3}	4.2×10^{-3}	4.2×10^{-3}	8.0×10^{-3}	4.2×10^{-3}	4.2×10^{-3}	4.2×10^{-3}
Fatalities	0.018	0.039	0.039	0.048	0.039	0.039	0.039
OREGON							
Shipments							
Truck (originating/total)	195/3,324	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	33/649	33/649	33/649	33/649	33/649	33/649
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.3\times10^{1}/1.2\times10^{-2}$	$3.7\times10^{0}/1.8\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$	$3.7\times10^{0}/1.8\times10^{-3}$	$4.4\times10^{0}/2.2\times10^{-3}$
Workers (person-rem/LCFs)	$7.9\times10^{1}/3.2\times10^{-2}$	$1.8\times10^{1}/7.3\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$	$1.8\times10^{1}/7.3\times10^{-3}$	$1.8\times10^{1}/7.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.4\times10^{-4}/2.2\times10^{-7}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$2.5\times10^{-3}/1.2\times10^{-6}$	$1.7\times10^{-3}/8.5\times10^{-7}$	$2.5\times10^{-3}/1.2\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.5×10^{-3}	1.7×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	1.7×10^{-3}	2.1×10^{-3}
Fatalities	0.048	0.023	0.022	0.022	0.022	0.023	0.022

Table J-80. Estimated transportation impacts for the States of Idaho, Oregon, and Washington (page 2 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[d]	Apex[e]
WASHINGTON							
Shipments							
Truck (originating/total)	3,129/3,324	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	616/616	616/616	616/616	616/616	616/616	616/616
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$9.7\times10^{0}/4.9\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$
Workers (person-rem/LCFs)	$7.6\times10^{1}/3.0\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$	$3.2\times10^{1}/1.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$8.8\times10^{-4}/4.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$	$6.7\times10^{-4}/3.4\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.7×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}
Fatalities	0.001	0.005	0.005	0.005	0.005	0.005	0.005

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

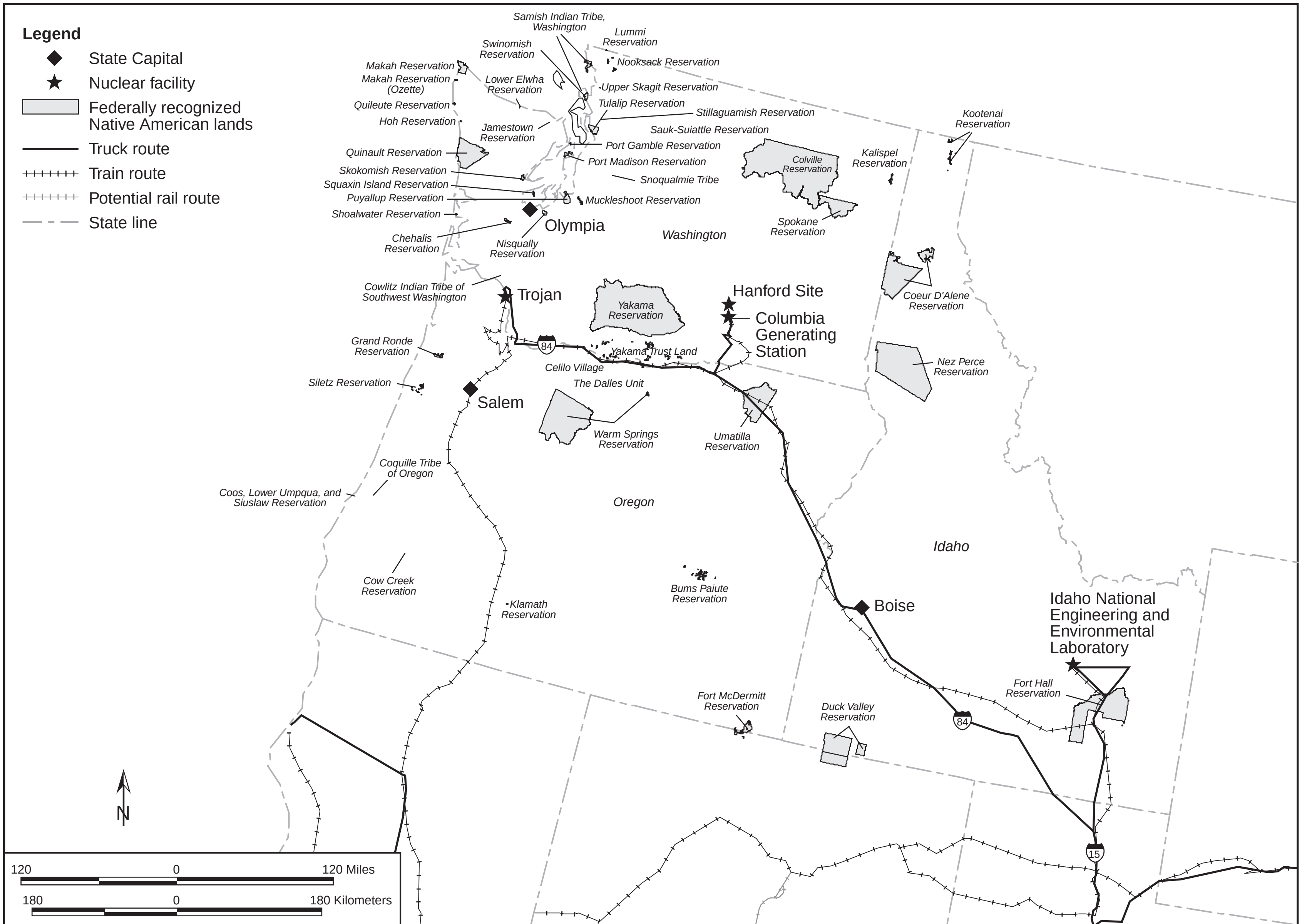
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-40. Highway and rail routes used to analyze transportation impacts - Idaho, Oregon, and Washington.

Table J-81. Estimated transportation impacts for the States of Indiana, Michigan, and Ohio (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[d]	Apex[e]
INDIANA							
Shipments							
Truck (originating/total)	0/17,258	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	0/5,980	0/5,980	0/5,778	0/5,980	0/5,980	0/5,980
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.2\times10^{2}/6.0\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.4\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$
Workers (person-rem/LCFs)	$2.5\times10^{2}/9.9\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$7.9\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$	$8.1\times10^{1}/3.2\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$8.8\times10^{-3}/4.4\times10^{-6}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.3\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$	$2.4\times10^{-2}/1.2\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.5×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	2.6×10^{-2}
Fatalities	0.05	0.12	0.12	0.12	0.12	0.12	0.12
MICHIGAN							
Shipments							
Truck (originating/total)	1,728/1,728	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	287/287	287/287	287/287	287/287	287/287	287/287
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$8.7\times10^{0}/4.3\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$	$4.7\times10^{0}/2.4\times10^{-3}$
Workers (person-rem/LCFs)	$4.9\times10^{1}/2.0\times10^{-2}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$6.0\times10^{-4}/3.0\times10^{-7}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$	$4.9\times10^{-3}/2.4\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.6×10^{-3}
Fatalities	0.006	0.010	0.010	0.010	0.010	0.010	0.010
OHIO							
Shipments							
Truck (originating/total)	636/12,121	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	106/2,381	106/2,381	106/2,381	106/2,381	106/2,381	106/2,381
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.6\times10^{2}/7.9\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$	$8.5\times10^{1}/4.3\times10^{-2}$
Workers (person-rem/LCFs)	$3.2\times10^{2}/1.3\times10^{-1}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$	$9.1\times10^{1}/3.6\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$7.7\times10^{-3}/3.8\times10^{-6}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$	$2.6\times10^{-2}/1.3\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.1×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}	3.9×10^{-2}
Fatalities	0.04	0.08	0.08	0.08	0.08	0.08	0.08

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

Table J-81. Estimated transportation impacts for the States of Indiana, Michigan, and Ohio (page 2 of 2).

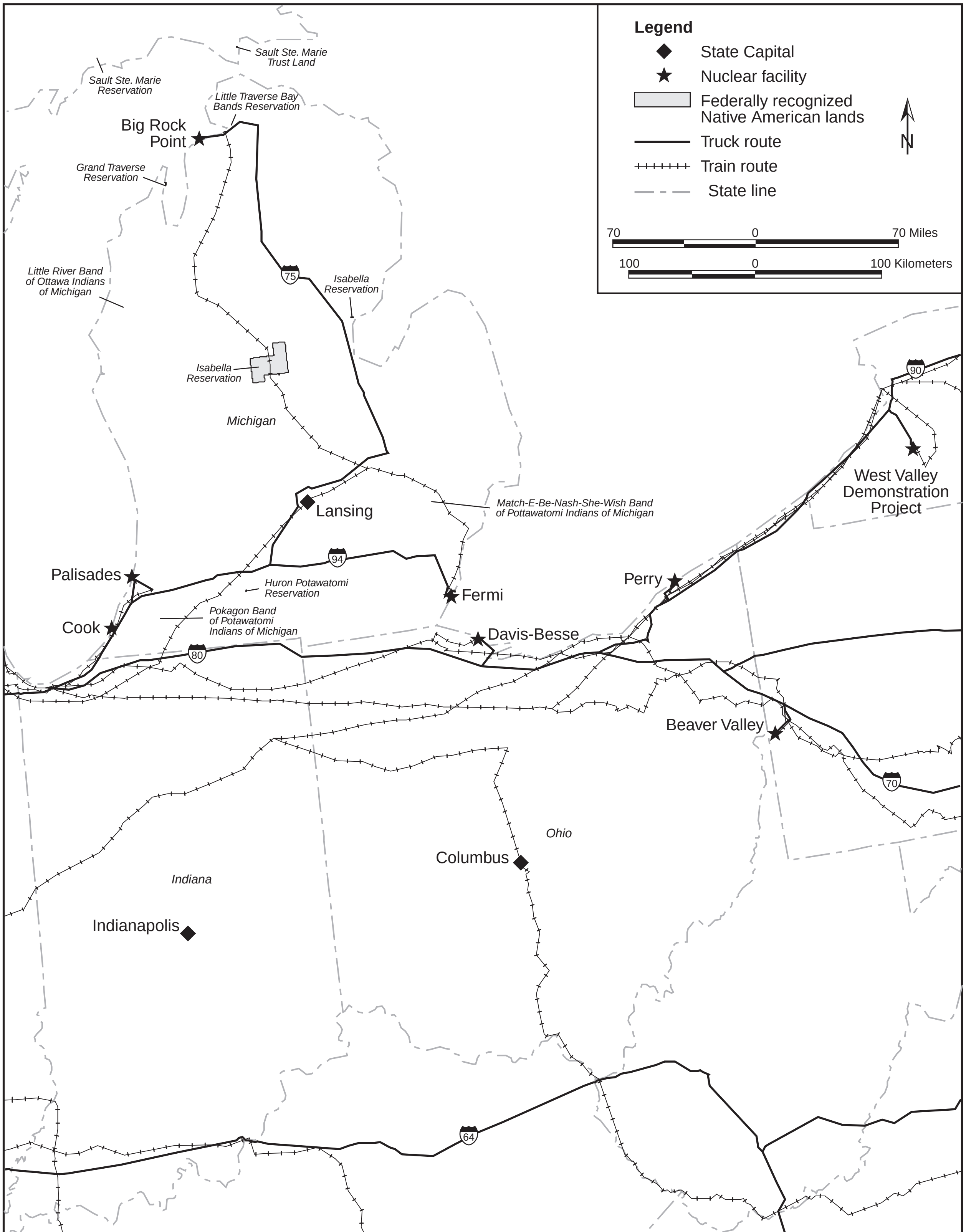
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

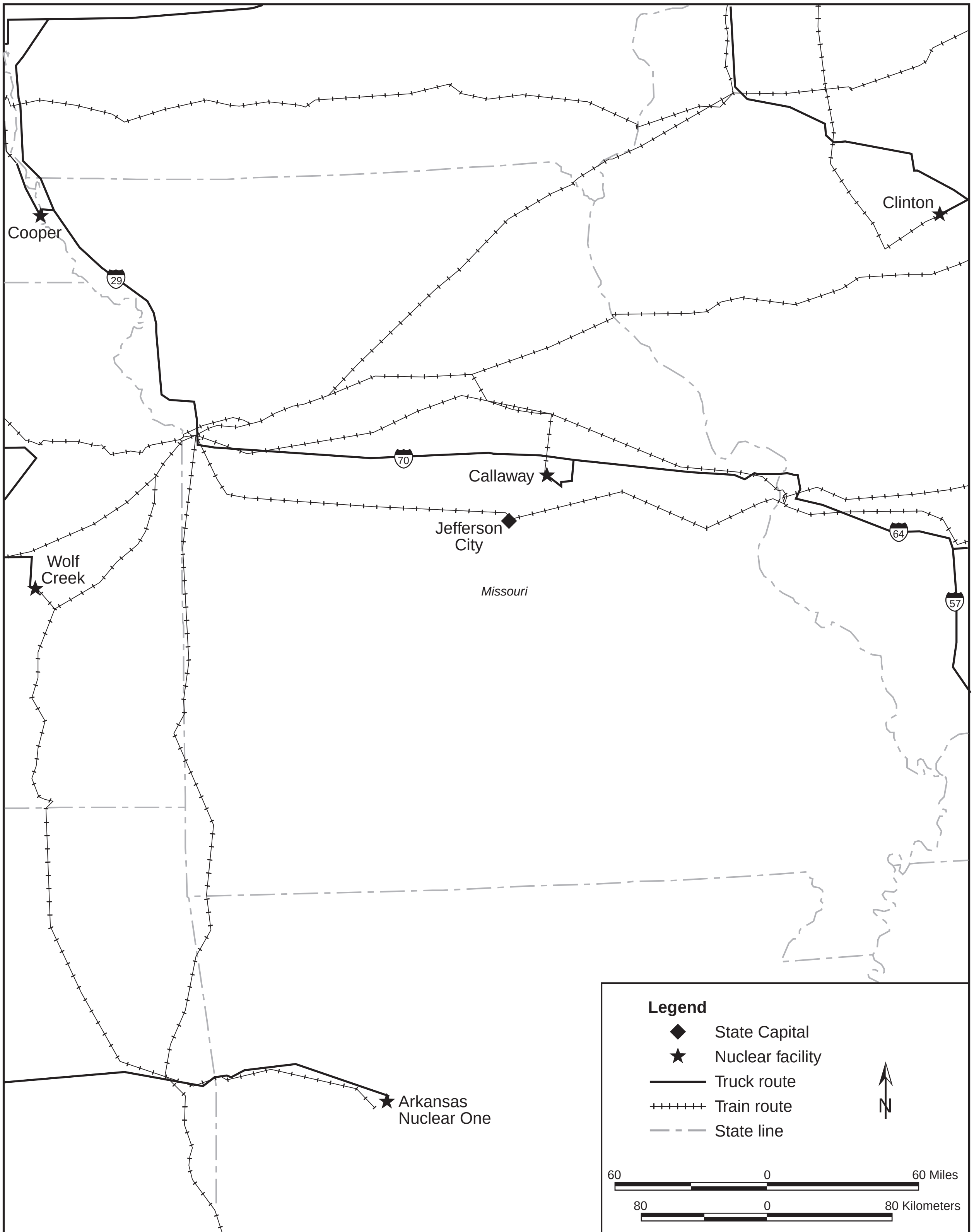
g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-41. Highway and rail routes used to analyze transportation impacts - Indiana, Michigan, and Ohio.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-47. Highway and rail routes used to analyze transportation impacts - Missouri.

Table J-88. Estimated transportation impacts for the States of Montana, North Dakota, and South Dakota (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MONTANA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk							
Population (person-rem/LCFs)	0	0	0	0	0	0	0
Nonradiological impacts							
Vehicle emissions (LCFs)	0	0	0	0	0	0	0
Fatalities	0	0	0	0	0	0	0
NORTH DAKOTA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Workers (person-rem/LCFs)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Accident dose risk							
Population (person-rem/LCFs)	0	0	0	0	0	0	0
Nonradiological impacts							
Vehicle emissions (LCFs)	0	0	0	0	0	0	0
Fatalities	0	0	0	0	0	0	0
SOUTH DAKOTA							
Shipments							
Truck (originating/total)	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/32	0/32	0/32	0/32	0/32	0/32
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$0.0\times10^{0}/0.0\times10^{0}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$	$1.8\times10^{-3}/9.0\times10^{-7}$
Workers (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}/2.0\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$	$4.0\times10^{-2}1.6\times10^{-5}$	$4.0\times10^{-2}/1.6\times10^{-5}$
Accident dose risk							
Population (person-rem/LCFs)	$0.0\times10^{0}/0.0\times10^{0}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$	$7.3\times10^{-6}/3.7\times10^{-9}$
Nonradiological impacts							
Vehicle emissions (LCFs)	0.00×10^{0}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}	1.04×10^{-6}
Fatalities	0.0×10^{0}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

Table J-88. Estimated transportation impacts for the States of Montana, North Dakota, and South Dakota (page 2 of 2).

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

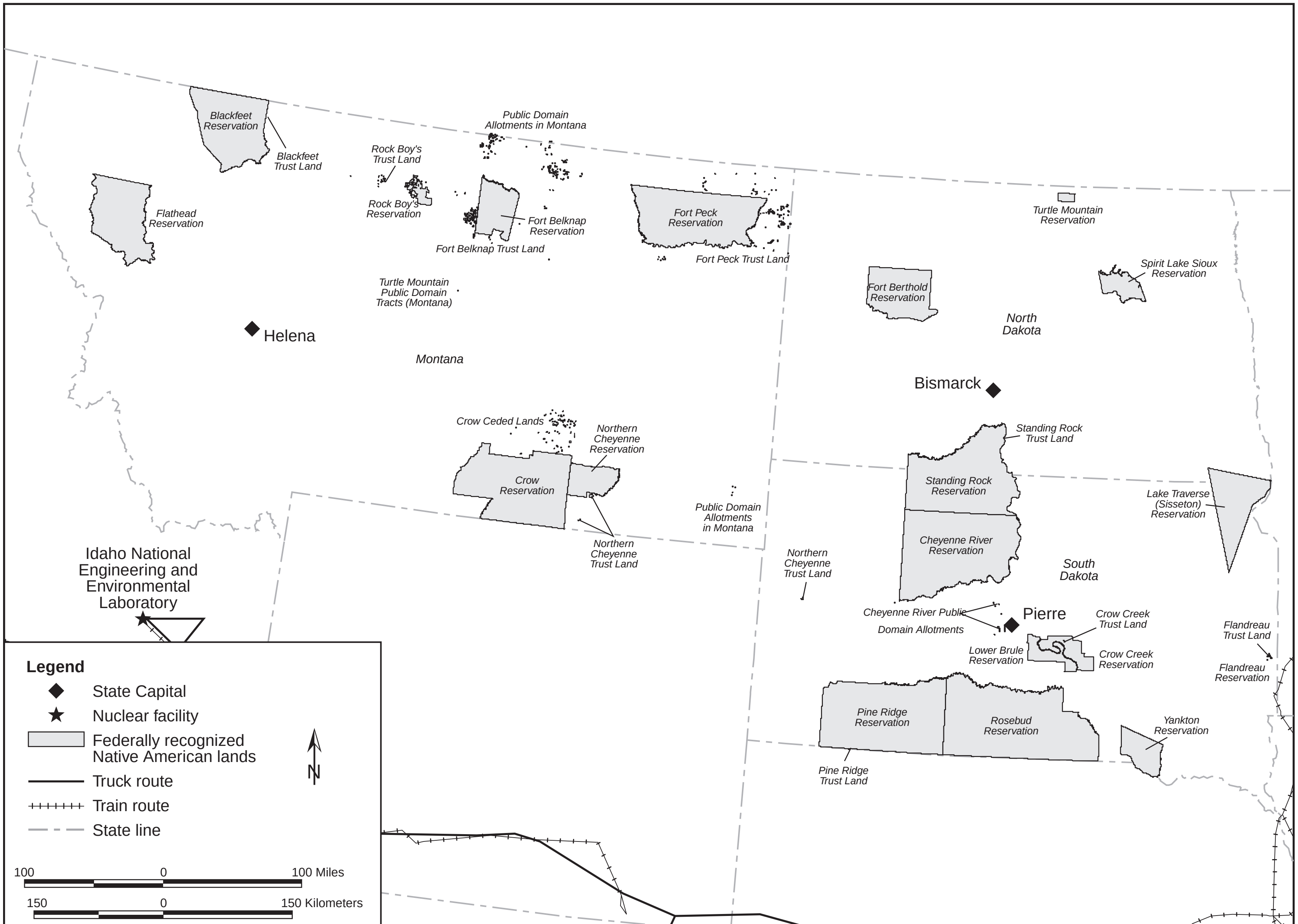
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-48. Highway and rail routes used to analyze transportation impacts - Montana, North Dakota, and South Dakota.

Table J-89. Estimated transportation impacts for the States of New Jersey and Pennsylvania.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a] — Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
NEW JERSEY							
Shipments							
Truck (originating/total)	1,528/3,245	0/335	0/335	0/335	0/335	0/335	0/335
Rail (originating/total)	0/0	244/244	244/244	244/244	244/244	244/244	244/244
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.2\times10^{1}/6.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$	$1.0\times10^{1}/5.1\times10^{-3}$
Workers (person-rem/LCFs)	$4.6\times10^{1}/1.8\times10^{-2}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$	$1.7\times10^{1}/6.9\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.9\times10^{-3}/1.5\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$	$1.3\times10^{-2}/6.7\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.3×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}
Fatalities	0.007	0.022	0.022	0.022	0.022	0.022	0.022
PENNSYLVANIA							
Shipments							
Truck (originating/total)	3,803/11,485	0/580	0/580	0/580	0/580	0/580	0/580
Rail (originating/total)	0/0	661/2,078	661/2,078	661/2,078	661/2,078	661/2,078	661/2,078
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.0\times10^{2}/5.1\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$	$6.9\times10^{1}/3.4\times10^{-2}$
Workers (person-rem/LCFs)	$3.1\times10^{2}/1.2\times10^{-1}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$	$9.4\times10^{1}/3.8\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.0\times10^{-2}/5.1\times10^{-6}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$	$5.5\times10^{-2}/2.7\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.3×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}	2.9×10^{-2}
Fatalities	0.099	0.066	0.066	0.066	0.066	0.066	0.066

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

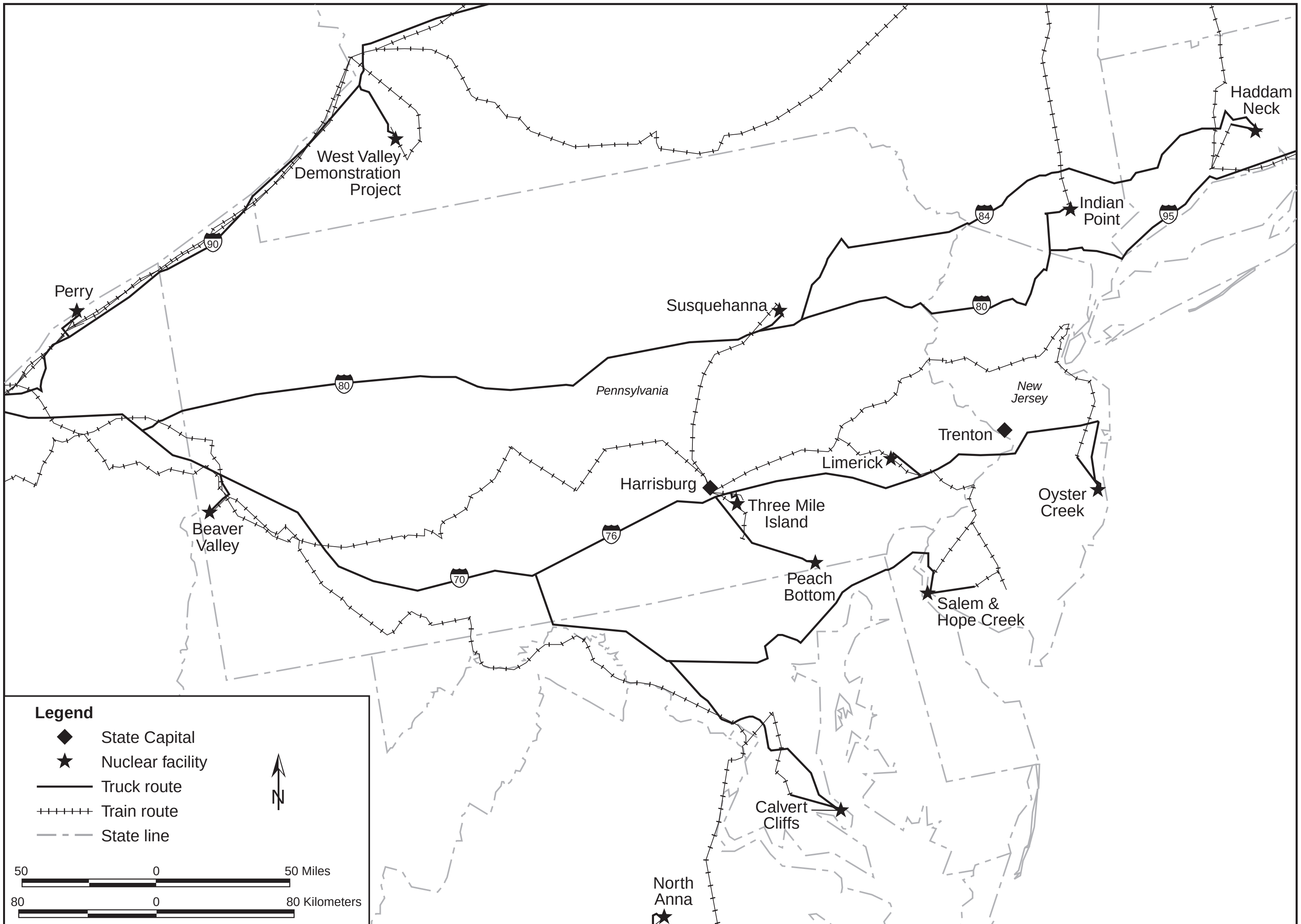
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-49. Highway and rail routes used to analyze transportation impacts - New Jersey and Pennsylvania.

Table J-90. Estimated transportation impacts for the States of North Carolina and South Carolina.

		Mostly rail					
		Ending rail node in Nevada[a]					
Impact category	Mostly legal-weight truck	Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
NORTH CAROLINA							
Shipments							
Truck (originating/total)	1,871/2,508	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	486/943	486/943	486/943	486/943	486/943	486/943
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.7\times10^{1}/1.4\times10^{-2}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$	$1.1\times10^{1}/5.7\times10^{-3}$
Workers (person-rem/LCFs)	$8.4\times10^{1}/3.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$	$3.4\times10^{1}/1.4\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$3.5\times10^{-3}/1.7\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.3×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}	4.1×10^{-3}
Fatalities	0.023	0.052	0.052	0.052	0.052	0.052	0.052
SOUTH CAROLINA							
Shipments							
Truck (originating/total)	9,832/9,832	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385	1,899/2,385
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.3\times10^{1}/6.5\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$	$1.8\times10^{1}/8.9\times10^{-3}$
Workers (person-rem/LCFs)	$2.1\times10^{2}/8.4\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$	$1.1\times10^{2}/4.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.1\times10^{-3}/5.4\times10^{-7}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$	$4.6\times10^{-3}/2.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.4×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}	4.3×10^{-3}
Fatalities	0.03	0.08	0.08	0.08	0.08	0.08	0.08

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

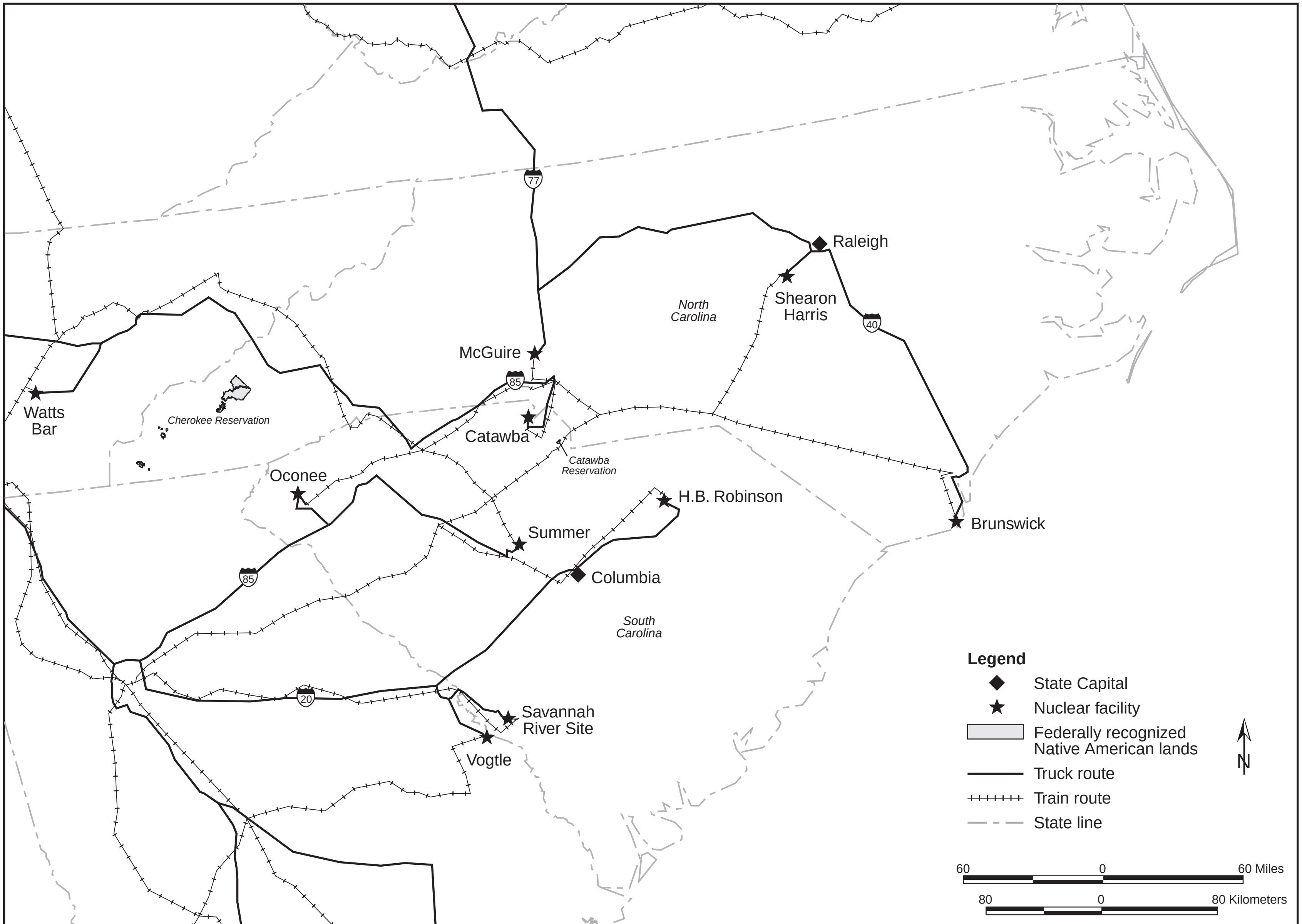
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-50. Highway and rail routes used to analyze transportation impacts - North Carolina and South Carolina.

Table J-91. Estimated transportation impacts for the States of Oklahoma and Texas.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
OKLAHOMA							
Shipments							
Truck (originating/total)	0/3,471	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	0/412	0/355	0/399	0/439	0/478	0/201
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.1\times10^{1}/2.0\times10^{-2}$	$4.1\times10^{-1}/2.0\times10^{-4}$	$4.1\times10^{-1}/2.0\times10^{-4}$	$3.3\times10^{-1}/1.6\times10^{-4}$	$5.2\times10^{-1}2.6\times10^{-4}$	$4.0\times10^{-1}/2.0\times10^{-4}$	$4.0\times10^{-1}/2.0\times10^{-4}$
Workers (person-rem/LCFs)	$1.1\times10^{2}/4.2\times10^{-2}$	$3.9\times10^{0}/1.5\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$5.3\times10^{0}/2.1\times10^{-3}$	$4.5\times10^{0}/1.8\times10^{-3}$	$3.0\times10^{0}/1.7\times10^{-3}$	$3.0\times10^{0}/1.2\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.6\times10^{-3}/1.3\times10^{-6}$	$3.4\times10^{-4}/1.7\times10^{-7}$	$3.4\times10^{-4}/1.7\times10^{-7}$	$3.1\times10^{-4}/1.6\times10^{-7}$	$4.2\times10^{-4}/2.1\times10^{-7}$	$3.5\times10^{-4}/1.7\times10^{-7}$	$3.3\times10^{-4}/1.6\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	6.4×10^{-3}	2.3×10^{-4}	2.3×10^{-4}	1.8×10^{-4}	2.9×10^{-4}	2.3×10^{-4}	2.3×10^{-4}
Fatalities	0.043	0.005	0.005	0.007	0.006	0.006	0.004
TEXAS							
Shipments							
Truck (originating/total)	1,193/3,999	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	269/472	269/472	269/952	269/472	269/472	269/472
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$7.9\times10^{1}/4.0\times10^{-2}$	$1.8\times10^{1}/9.1\times10^{-3}$	$1.9\times10^{1}/9.3\times10^{-3}$	$4.1\times10^{1}/2.0\times10^{-2}$	$1.9\times10^{1}/9.6\times10^{-3}$	$1.8\times10^{1}/9.0\times10^{-3}$	$2.1\times10^{1}/1.0\times10^{-2}$
Workers (person-rem/LCFs)	$1.9\times10^{2}/7.6\times10^{-2}$	$4.4\times10^{1}/1.8\times10^{-2}$	$4.5\times10^{1}/1.8\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$3.9\times10^{1}/1.5\times10^{-2}$	$4.3\times10^{1}/1.7\times10^{-2}$	$4.8\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.7\times10^{-2}/8.6\times10^{-6}$	$7.0\times10^{-3}/3.5\times10^{-6}$	$7.3\times10^{-3}/3.7\times10^{-6}$	$2.0\times10^{-2}/9.9\times10^{-6}$	$7.2\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.5\times10^{-6}$	$8.1\times10^{-3}/4.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.96×10^{-2}	7.47×10^{-3}	7.77×10^{-3}	1.87×10^{-2}	8.10×10^{-3}	7.60×10^{-3}	8.84×10^{-3}
Fatalities	0.07	0.05	0.05	0.14	0.04	0.05	0.05

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

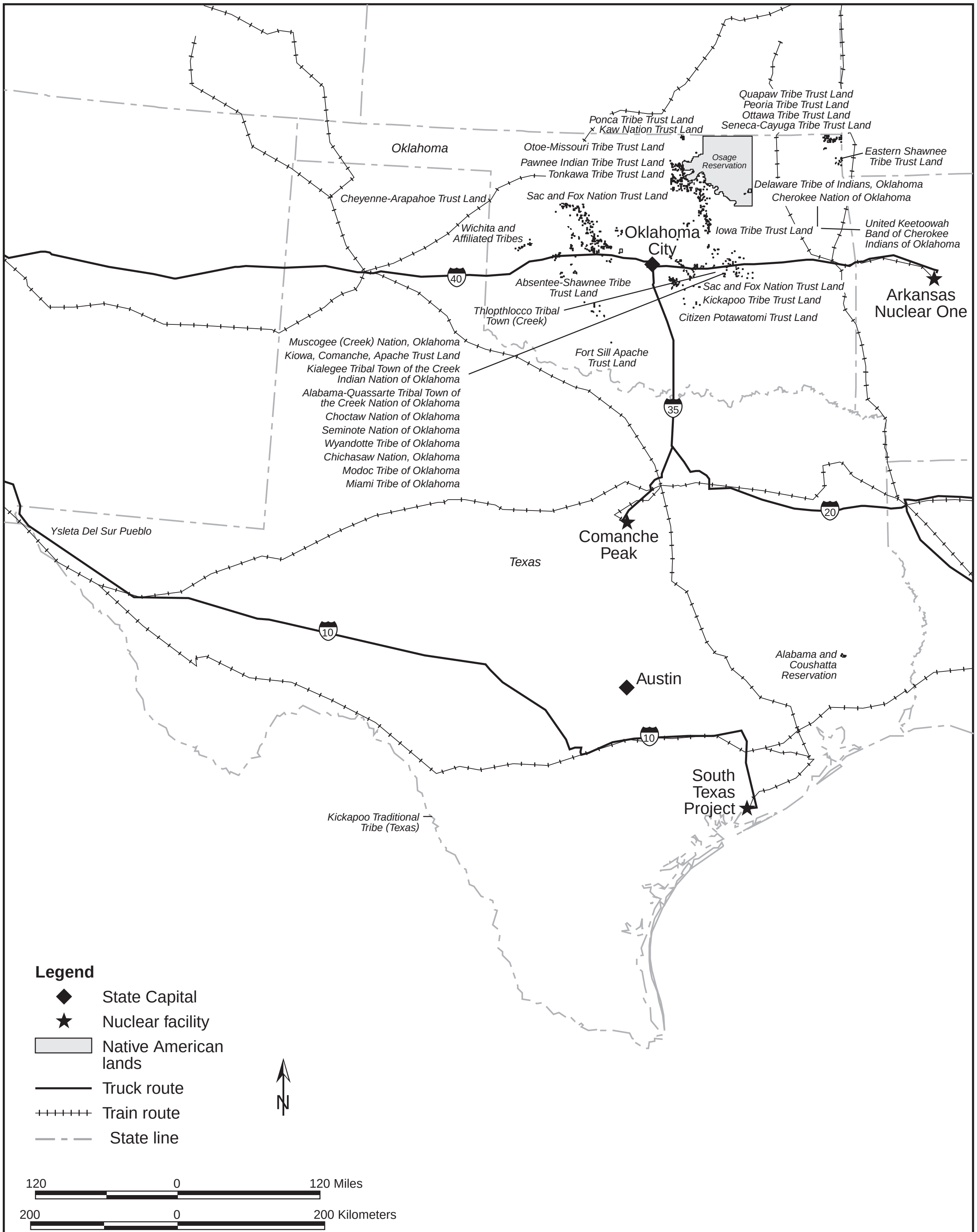
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-51. Highway and rail routes used to analyze transportation impacts - Oklahoma and Texas.

Table J-92. Estimated transportation impacts for the States of Utah and Wyoming.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
UTAH							
Shipments							
Truck (originating/total)	0/45,919	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/300	0/8,986	0/8,896	0/8,182	0/9,134	0/9,052	0/8,742
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$9.6\times10^{2}/4.8\times10^{-1}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.1\times10^{3}/5.6\times10^{-1}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.8\times10^{2}/8.8\times10^{-2}$	$1.7\times10^{2}/8.6\times10^{-2}$
Workers (person-rem/LCFs)	$1.9\times10^{3}/7.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$2.2\times10^{3}/8.8\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$	$3.6\times10^{2}/1.4\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$1.0\times10^{-1}/5.2\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$1.8\times10^{-1}/8.8\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$	$7.2\times10^{-2}/3.6\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.8×10^{-1}	8.7×10^{-2}	8.7×10^{-2}	3.6×10^{-1}	8.7×10^{-2}	8.7×10^{-2}	8.4×10^{-2}
Fatalities	0.71	0.58	0.58	1.25	0.58	0.58	0.57
WYOMING							
Shipments							
Truck (originating/total)	0/41,507	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/0	0/7,347	0/7,347	0/7,065	0/7,440	0/7,347	0/7,347
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$5.4\times10^{2}/2.7\times10^{-1}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.3\times10^{1}/2.1\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$	$4.4\times10^{1}/2.2\times10^{-2}$
Workers (person-rem/LCFs)	$1.7\times10^{3}/6.9\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.7\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$	$3.8\times10^{2}/1.5\times10^{-1}$
Accident dose risk							
Population (person-rem/LCFs)	$3.9\times10^{-2}/1.9\times10^{-5}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$6.8\times10^{-3}/3.4\times10^{-6}$	$7.2\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$	$7.1\times10^{-3}/3.6\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	38.7×10^{-3}	15.9×10^{-3}	15.9×10^{-3}	15.4×10^{-3}	16.1×10^{-3}	15.9×10^{-3}	15.9×10^{-3}
Fatalities	0.58	0.06	0.06	0.06	0.06	0.06	0.06

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

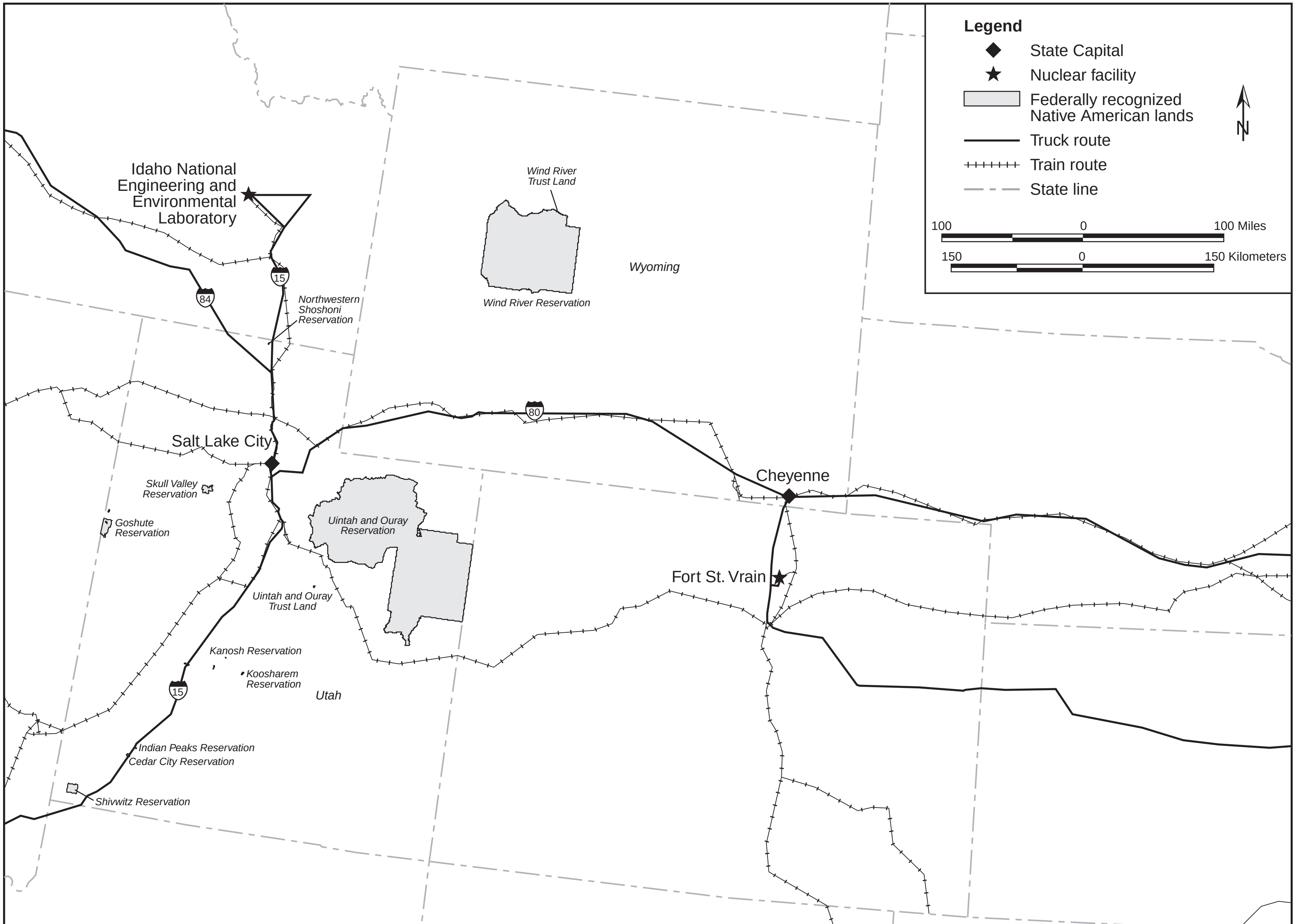
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

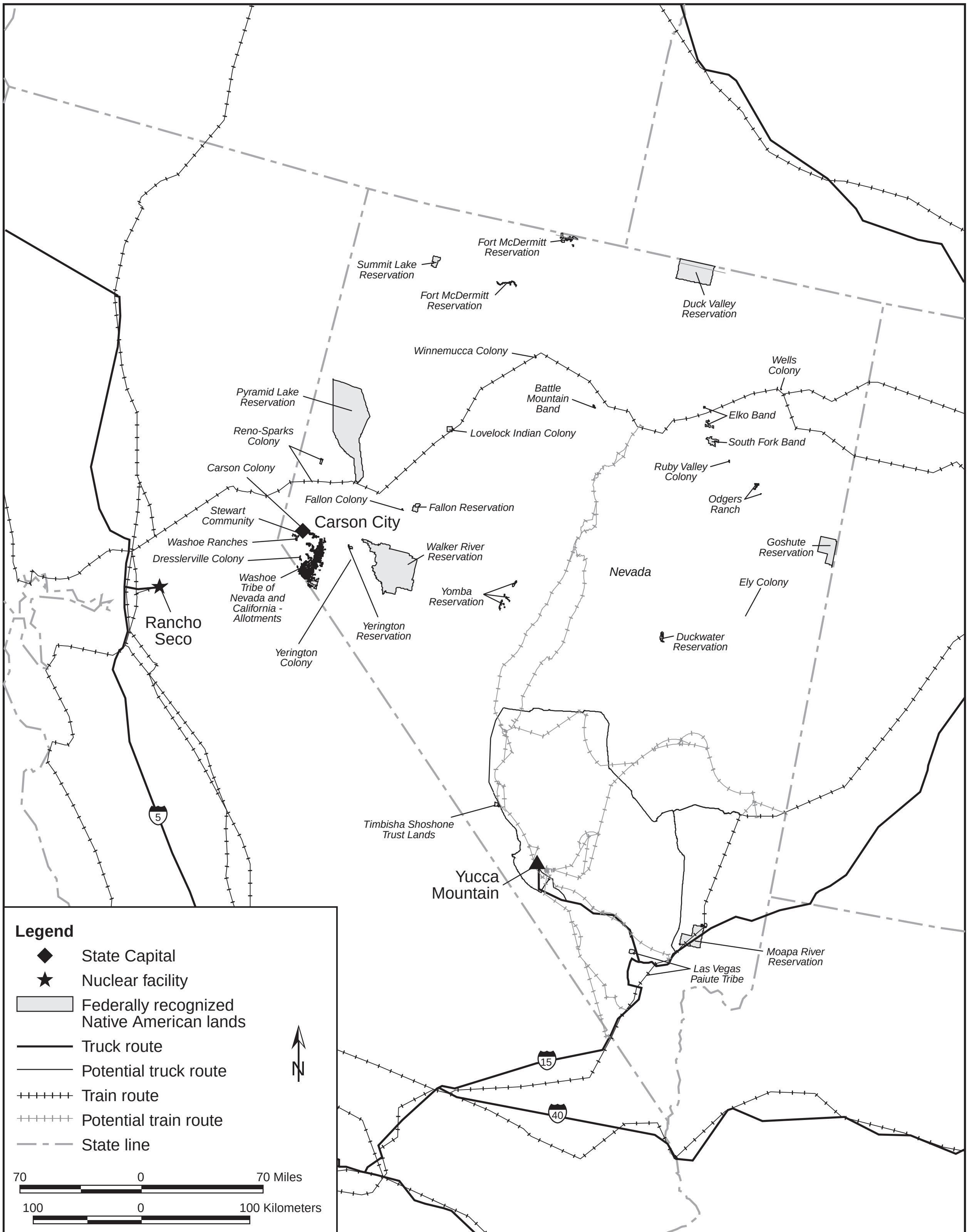
Figure J-52. Highway and rail routes used to analyze transportation impacts - Utah and Wyoming.

Table J-93. Estimated transportation impacts for the State of Nevada.

Impact category	Mostly legal-weight truck	Mostly rail									
		Rail implementing alternatives					Heavy-haul implementing alternatives				
		Caliente	Carlin	Caliente-Chalk Mountain	Jean	Valley Modified	Caliente	Caliente/Chalk Mountain	Caliente/Las Vegas	Sloan/Jean	Apex/Dry Lake
NEVADA											
Shipments											
Truck (originating/total)	0/52,786	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079	0/1,079
Rail (originating/total)	0/300	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646	0/9,646
Radiological impacts											
Incident-free impacts											
Population (person-rem/LCFs)[a]	3.5×10^{2}/ 1.8×10^{-1}	1.9×10^{1}/ 9.4×10^{-3}	3.8×10^{1}/ 1.9×10^{-2}	$1.8 \times 10^{1}/9.1 \times 10^{-3}$	1.6×10^{2}/ 7.8×10^{-2}	2.6×10^{1}/ 1.3×10^{-2}	7.9×10^{1}/ 3.9×10^{-2}	$6.3 \times 10^{1}/3.2 \times 10^{-2}$	2.2×10^{2}/ 1.1×10^{-1}	3.3×10^{2}/ 1.7×10^{-1}	1.6×10^{2}/ 7.8×10^{-2}
Workers (person-rem/ LCFs)	1.9×10^{3}/ 7.5×10^{-1}	8.3×10^{2}/ 3.3×10^{-1}	9.6×10^{2}/ 3.8×10^{-1}	$7.3 \times 10^{2}/2.9 \times 10^{-1}$	7.4×10^{2}/ 3.0×10^{-1}	7.0×10^{2}/ 2.8×10^{-1}	1.4×10^{3}/ 5.5×10^{-1}	$9.8 \times 10^{2}/3.9 \times 10^{-1}$	1.1×10^{3}/ 4.5×10^{-1}	9.3×10^{2}/ 3.7×10^{-1}	8.9×10^{2}/ 3.5×10^{-1}
Accident dose risk											
Population (person-rem/LCFs)	5.3×10^{-2}/ 2.6×10^{-5}	1.7×10^{-3}/ 8.6×10^{-7}	2.6×10^{-3}/ 1.3×10^{-6}	$1.7 \times 10^{-3}/8.5 \times 10^{-7}$	7.1×10^{-3}/ 3.6×10^{-6}	2.1×10^{-3}/ 1.0×10^{-6}	1.0×10^{-2}/ 5.1×10^{-6}	$2.0 \times 10^{-3}/1.0\times 10^{-6}$	5.6×10^{-2}/ 2.8×10^{-5}	1.2×10^{-1}/ 6.0×10^{-5}	5.6×10^{-2}/ 2.8×10^{-5}
Nonradiological impacts											
Vehicle emissions (LCFs)	9.3×10^{-2}	7.1×10^{-3}	1.8×10^{-2}	7.7×10^{-3}	7.7×10^{-2}	1.1×10^{-2}	1.6×10^{-2}	7.9×10^{-3}	6.4×10^{-2}	1.9×10^{-1}	6.6×10^{-2}
Fatalities	0.49	0.07	0.09	0.05	0.06	0.05	0.60	0.33	0.43	0.25	0.23

a. Includes impacts of an intermodal transfer station.

b. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-53. Highway and rail routes used to analyze transportation impacts - Nevada.

Table J-82. Estimated transportation impacts for the State of Illinois.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
ILLINOIS							
Shipments							
Truck (originating/total)	5,306/38,549	0/1,071	0/1,071	0/1,071	0/1,071	0/1,071	0/1,071
Rail (originating/total)	0/0	861/7,027	861/7,027	861/6,825	861/7,027	861/7,027	861/7,027
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.8\times10^{2}/1.4\times10^{-1}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/7.4\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$	$1.8\times10^{2}/8.9\times10^{-2}$
Workers (person-rem/LCFs)	$7.6\times10^{2}/3.1\times10^{-1}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.8\times10^{2}/7.4\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$	$1.9\times10^{2}/7.5\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$1.6\times10^{-2}/8.1\times10^{-6}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.5\times10^{-1}/7.7\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$	$1.6\times10^{-1}/7.9\times10^{-5}$
Nonradiological impacts							
Vehicle emissions (LCFs)	4.5×10^{-2}	8.0×10^{-2}	8.0×10^{-2}	7.9×10^{-2}	8.0×10^{-2}	8.0×10^{-2}	8.0×10^{-2}
Fatalities	0.17	0.19	0.19	0.18	0.19	0.19	0.19

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

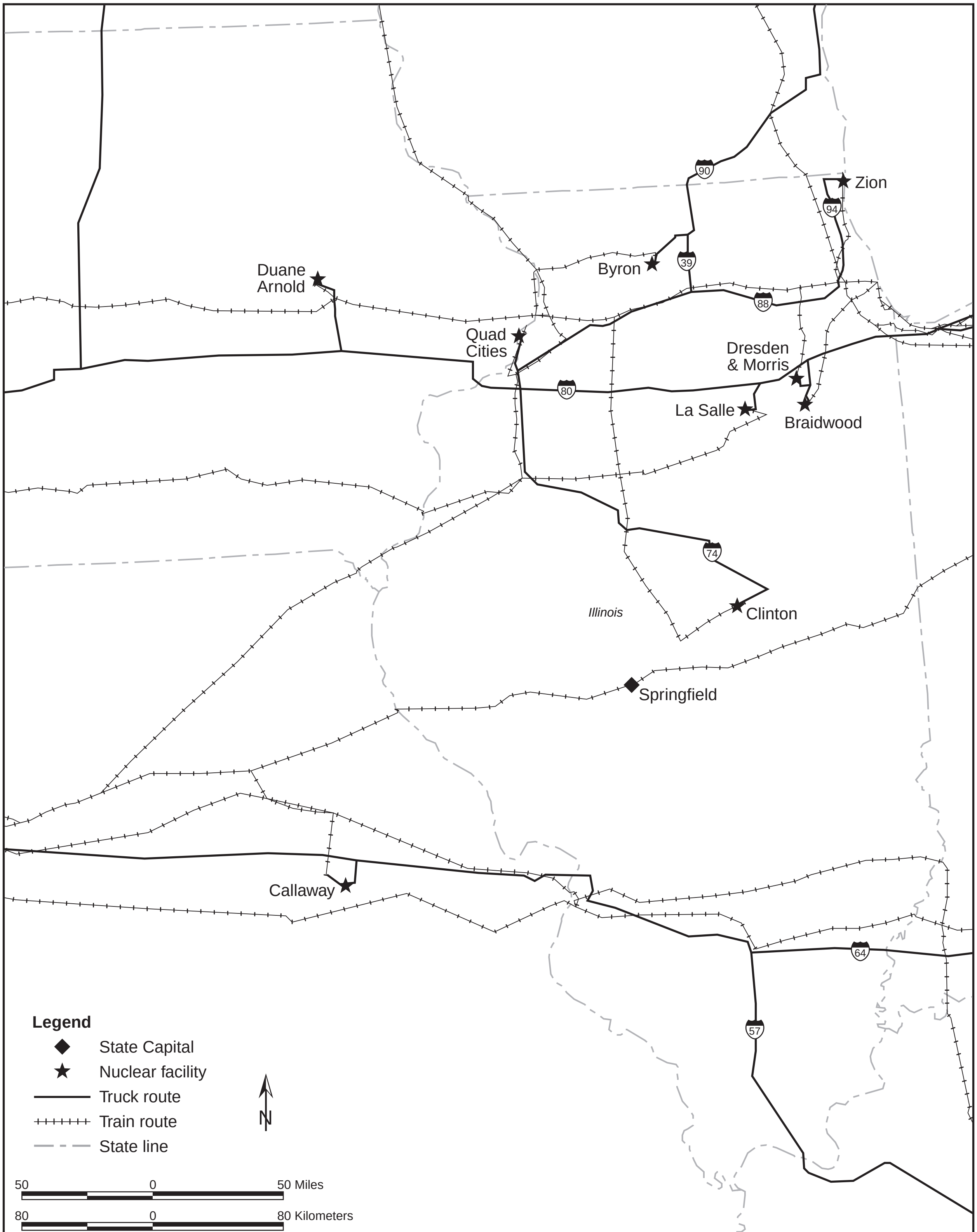
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-42. Highway and rail routes used to analyze transportation impacts - Illinois.

Table J-83. Estimated transportation impacts for the States of Kentucky and Tennessee.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
KENTUCKY							
Shipments							
Truck (originating/total)	0/18,435	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	0/3,312	0/3,312	0/3,110	0/3,312	0/3,312	0/3,312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$8.3\times10^{1}/4.2\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$1.9\times10^{1}/9.6\times10^{-3}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$	$2.0\times10^{1}/1.0\times10^{-2}$
Workers (person-rem/LCFs)	$2.2\times10^{2}/8.7\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.7\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$	$4.9\times10^{1}/1.9\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$5.2\times10^{-3}/2.6\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$3.9\times10^{-3}/2.0\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$3.9\times10^{-3}/2.0\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.1×10^{-2}	9.7×10^{-3}	9.7×10^{-3}	9.3×10^{-3}	9.7×10^{-3}	9.7×10^{-3}	9.7×10^{-3}
Fatalities	0.086	0.041	0.041	0.039	0.041	0.041	0.041
TENNESSEE							
Shipments							
Truck (originating/total)	802/15,026	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	121/3,312	121/3,312	121/3,110	121/3,312	121/3,312	121/3,312
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.4\times10^{2}/6.9\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.1\times10^{1}/2.5\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$	$5.5\times10^{1}/2.7\times10^{-2}$
Workers (person-rem/LCFs)	$3.1\times10^{2}/1.2\times10^{-1}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$7.7\times10^{1}/3.1\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$	$8.2\times10^{1}/3.3\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$4.7\times10^{-3}/2.4\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$9.0\times10^{-3}/4.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$	$1.1\times10^{-2}/5.5\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.8×10^{-2}	2.7×10^{-2}	2.7×10^{-2}	2.5×10^{2}	2.7×10^{-2}	2.7×10^{-2}	2.7×10^{-2}
Fatalities	0.09	0.07	0.07	0.07	0.07	0.07	0.07

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

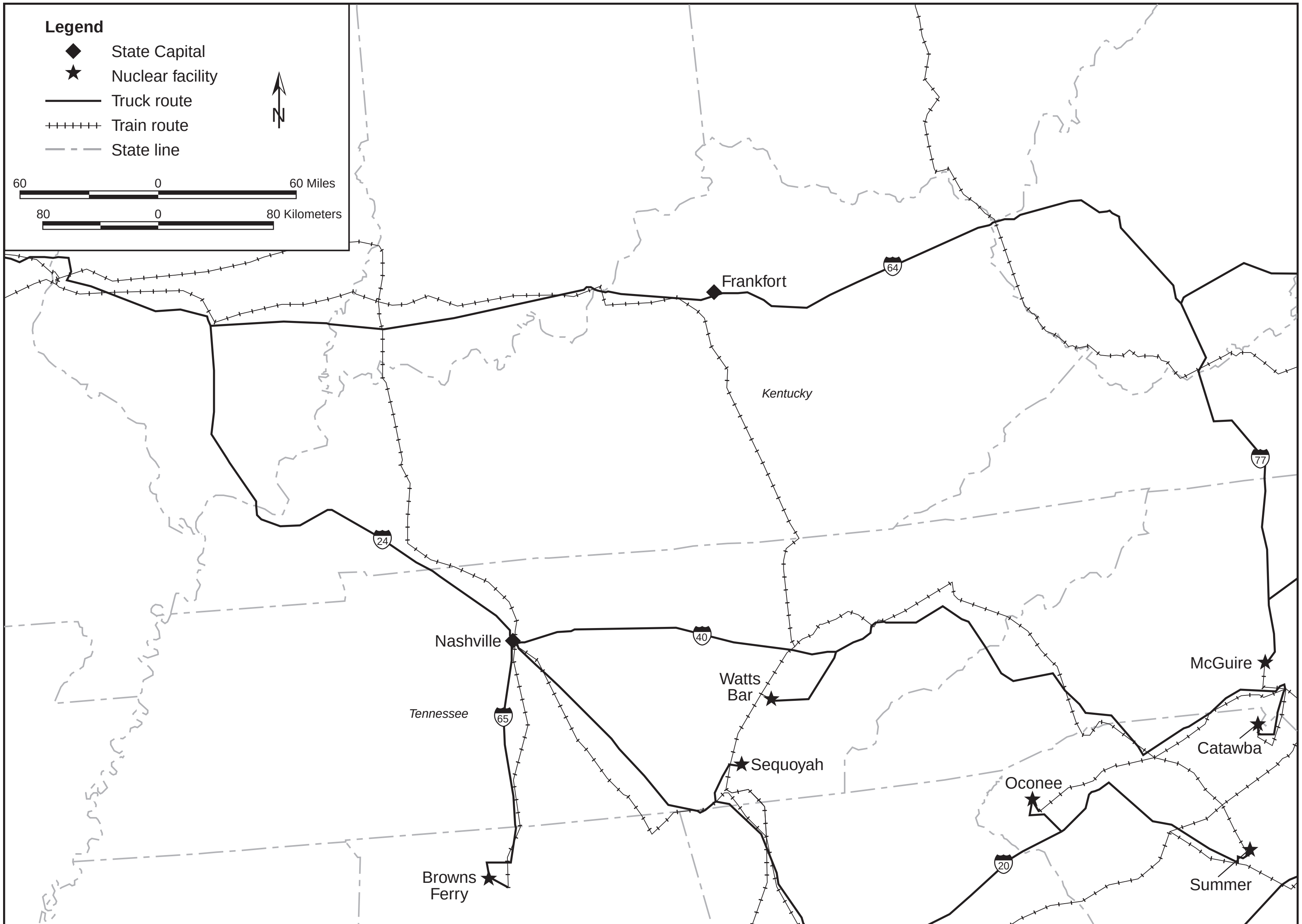
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-43. Highway and rail routes used to analyze transportation impacts - Kentucky and Tennessee.

Table J-84. Estimated transportation impacts for the States of Louisiana and Mississippi.

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[d]	Apex[e]
LOUISIANA							
Shipments							
Truck (originating/total)	727/2,012	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	123/203	123/203	123/405	123/203	123/203	123/203
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.6\times10^{1}/1.3\times10^{-2}$	$2.9\times10^{0}/1.5\times10^{-3}$	$2.6\times10^{0}/1.3\times10^{-3}$	$7.5\times10^{0}/3.8\times10^{-3}$	$3.0\times10^{0}/1.5\times10^{-3}$	$2.9\times10^{0}/1.5\times10^{-3}$	$2.6\times10^{0}/1.3\times10^{-3}$
Workers (person-rem/LCFs)	$7.7\times10^{1}/3.1\times10^{-2}$	$1.1\times10^{1}/4.3\times10^{-3}$	$1.0\times10^{1}/4.1\times10^{-3}$	$1.7\times10^{1}/6.7\times10^{-3}$	$1.1\times10^{1}/4.4\times10^{-3}$	$1.1\times10^{1}/4.3\times10^{-3}$	$1.0\times10^{1}/4.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$1.3\times10^{-3}/6.6\times10^{-7}$	$2.9\times10^{-3}/1.5\times10^{-6}$	$2.5\times10^{-3}/1.3\times10^{-6}$	$9.3\times10^{-3}/4.6\times10^{-6}$	$3.0\times10^{-3}/1.5\times10^{-6}$	$2.9\times10^{-3}/1.5\times10^{-6}$	$2.5\times10^{-3}/1.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.91×10^{-3}	1.06×10^{-3}	8.98×10^{-4}	3.31×10^{-3}	1.08×10^{-3}	1.06×10^{-3}	8.98×10^{-4}
Fatalities	0.018	0.018	0.016	0.037	0.018	0.018	0.016
MISSISSIPPI							
Shipments							
Truck (originating/total)	592/1,285	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	80/80	80/80	80/282	80/80	80/80	80/80
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$2.8\times10^{0}/1.4\times10^{-3}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$2.7\times10^{0}/1.3\times10^{-3}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$	$6.2\times10^{-1}/3.1\times10^{-4}$
Workers (person-rem/LCFs)	$1.8\times10^{1}/7.3\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$6.1\times10^{1}/2.4\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$	$4.3\times10^{0}/1.7\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.3\times10^{-5}/1.1\times10^{-8}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$3.3\times10^{-3}/1.7\times10^{-6}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$	$1.1\times10^{-5}/5.7\times10^{-9}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.7×10^{-4}	8.5×10^{-6}	8.5×10^{-6}	1.1×10^{-3}	8.5×10^{-6}	8.5×10^{-6}	8.5×10^{-6}
Fatalities	5.9×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	4.3×10^{-3}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

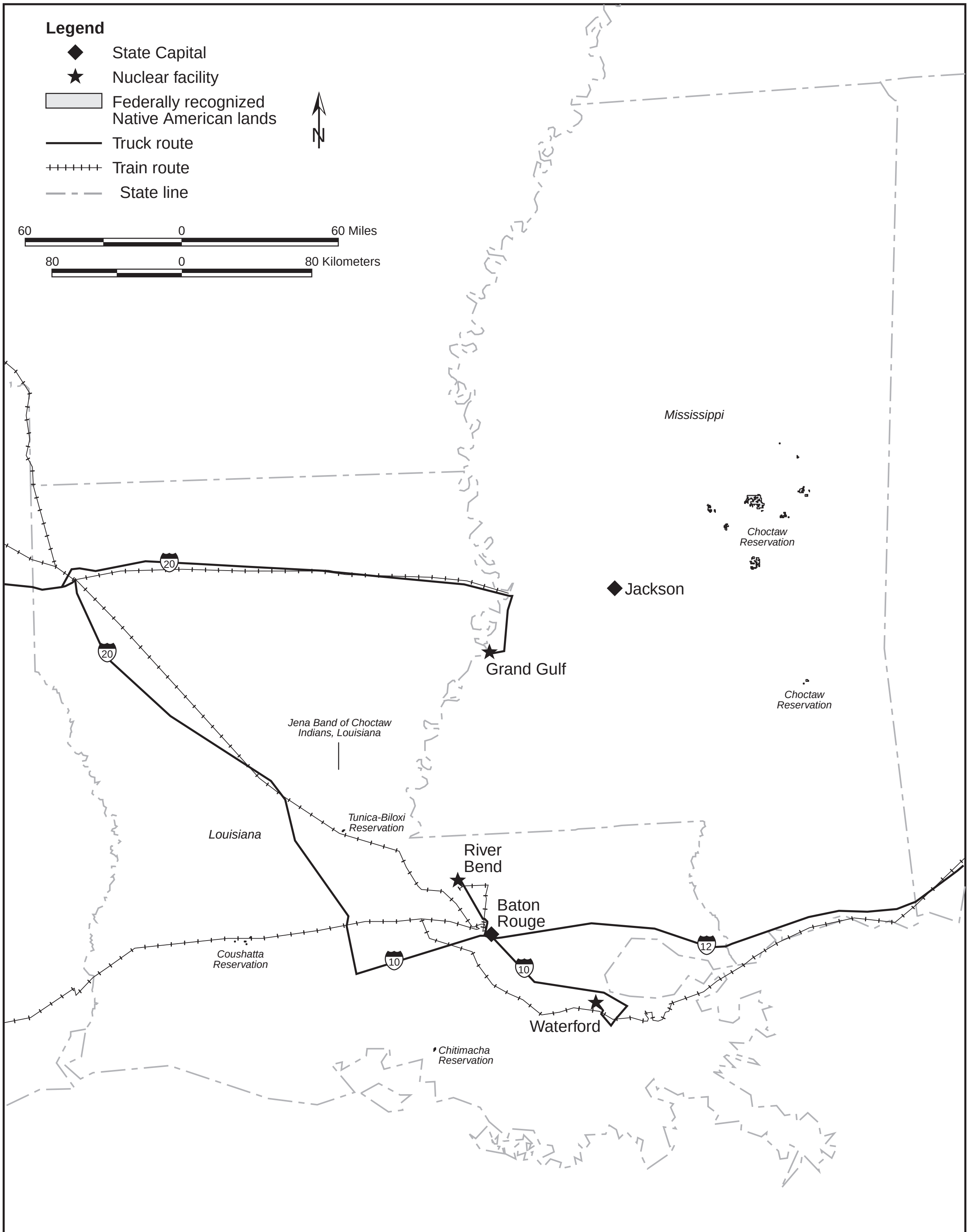
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-44. Highway and rail routes used to analyze transportation impacts - Louisiana and Mississippi.

Table J-85. Estimated transportation impacts for the States of Maine, Massachusetts, New Hampshire, and Vermont (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MAINE							
Shipments							
Truck (originating/total)	356/356	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	55/55	55/55	55/55	55/55	55/55	55/55
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.9\times10^{0}/9.5\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$	$5.2\times10^{-1}/2.6\times10^{-4}$
Workers (person-rem/LCFs)	$9.9\times10^{0}/4.0\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$	$3.2\times10^{0}/1.3\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.2\times10^{-4}/1.1\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$	$1.1\times10^{-3}/5.6\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	2.9×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}	1.7×10^{-4}
Fatalities	9.7×10^{-4}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}	2.9×10^{-3}
MASSACHUSETTS							
Shipments							
Truck (originating/total)	456/1,469	154/154	154/154	154/154	154/154	154/154	154/154
Rail (originating/total)	0/0	39/511	39/511	39/511	39/511	39/511	39/511
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.5\times10^{1}/7.3\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$	$7.9\times10^{0}/4.0\times10^{-3}$
Workers (person-rem/LCFs)	$3.0\times10^{1}/1.2\times10^{-2}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$	$1.3\times10^{1}/1.5\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.8\times10^{-4}/2.4\times10^{-7}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$	$1.5\times10^{-2}/7.3\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.7×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}
Fatalities	0.001	0.068	0.068	0.068	0.068	0.068	0.068
NEW HAMPSHIRE							
Shipments							
Truck (originating/total)	277/633	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	49/104	49/104	49/104	49/104	49/104	49/104
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[b]	$4.9\times10^{-1}/2.5\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$	$4.4\times10^{-1}/2.2\times10^{-4}$
Workers (person-rem/LCFs)	$5.7\times10^{0}/2.3\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$	$2.7\times10^{0}/1.1\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.2\times10^{-5}/2.1\times10^{-8}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$	$8.5\times10^{-4}/4.3\times10^{-7}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.9×10^{-5}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}	1.4×10^{-4}
Fatalities	1.2×10^{-4}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-3}

Table J-85. Estimated transportation impacts for the States of Maine, Massachusetts, New Hampshire, and Vermont (page 2 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada[a]					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
VERMONT							
Shipments							
Truck (originating/total)	380/380	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	73/192	73/192	73/192	73/192	73/192	73/192
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$4.1\times10^{-1}/2.1\times10^{-4}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$	$1.6\times10^{-1}/7.8\times10^{-5}$
Workers (person-rem/LCFs)	$7.5\times10^{0}/3.0\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$	$3.6\times10^{0}/1.4\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.4\times10^{-5}/1.2\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$	$7.0\times10^{-5}/3.5\times10^{-8}$
Nonradiological impacts							
Vehicle emissions (LCFs)	8.9×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}
Fatalities	1.1×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.5×10^{-4}

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

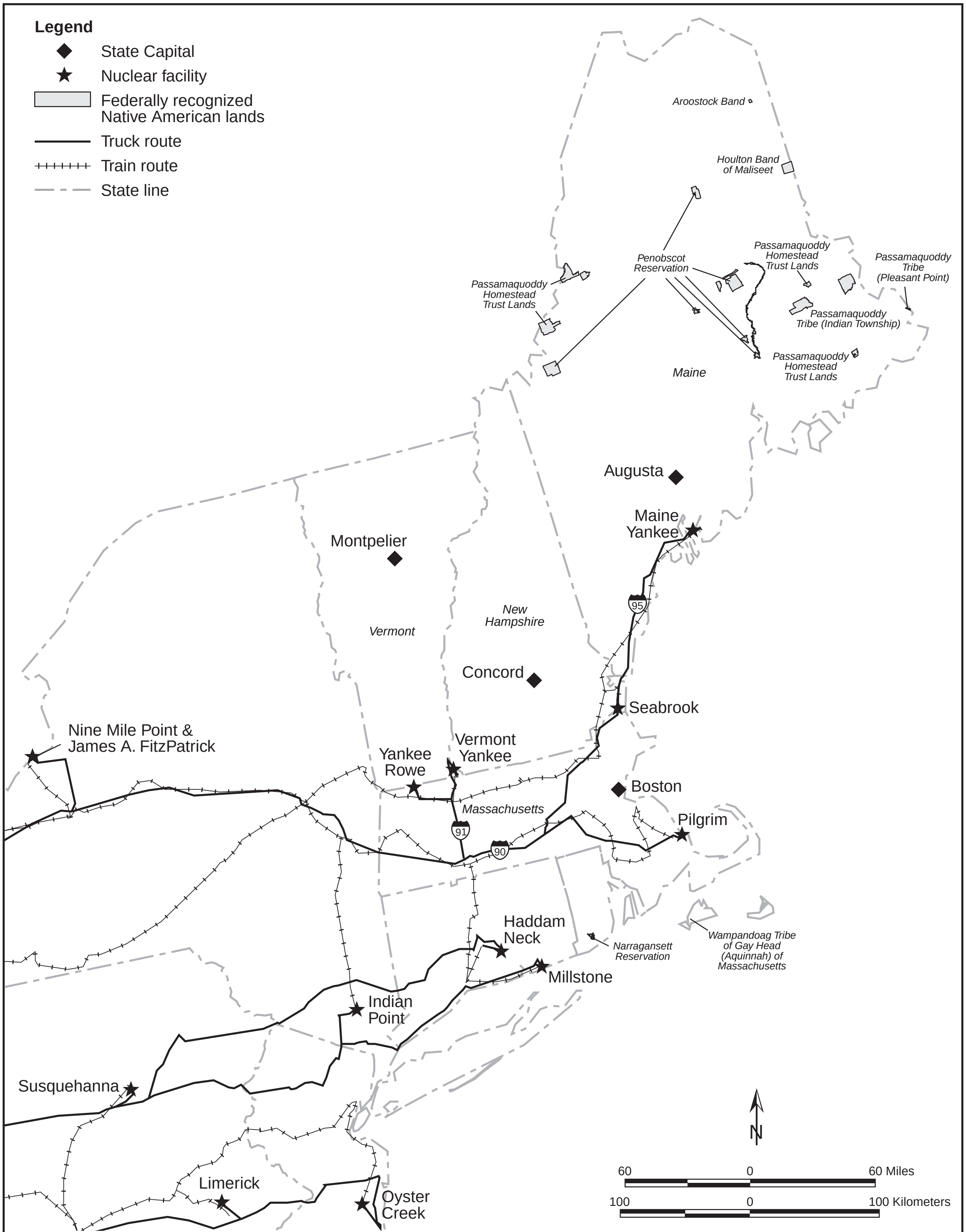
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-45. Highway and rail routes used to analyze transportation impacts - Maine, Massachusetts, New Hampshire, and Vermont.

Table J-86. Estimated transportation impacts for the States of Minnesota and Wisconsin (page 1 of 2).

Impact category	Mostly legal-weight truck	Mostly rail					
		Ending rail node in Nevada					
		Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MINNESOTA							
Shipments							
Truck (originating/total)	922/959	8/8	8/8	8/8	8/8	8/8	8/8
Rail (originating/total)	0/0	135/135	135/135	135/135	135/135	135/135	135/135
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$7.0\times10^{0}/3.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$	$3.1\times10^{0}/1.5\times10^{-3}$
Workers (person-rem/LCFs)	$3.1\times10^{1}/1.2\times10^{-2}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$	$9.9\times10^{0}/4.0\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$4.1\times10^{-4}/2.1\times10^{-7}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$	$2.2\times10^{-3}/1.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	1.5×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}	1.1×10^{-3}
Fatalities	1.4×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}	3.3×10^{-3}
WISCONSIN							
Shipments							
Truck (originating/total)	996/996	0/0	0/0	0/0	0/0	0/0	0/0
Rail (originating/total)	0/0	186/186	186/186	186/186	186/186	186/186	186/186
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$1.1\times10^{1}/5.7\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$	$4.5\times10^{0}/2.2\times10^{-3}$
Workers (person-rem/LCFs)	$3.7\times10^{1}/1.5\times10^{-2}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$	$1.3\times10^{1}/5.3\times10^{-3}$
Accident dose risk							
Population (person-rem/LCFs)	$2.3\times10^{-3}/1.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$	$4.2\times10^{-3}/2.1\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	3.4×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}	1.5×10^{-3}
Fatalities	0.005	0.006	0.006	0.006	0.006	0.006	0.006

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

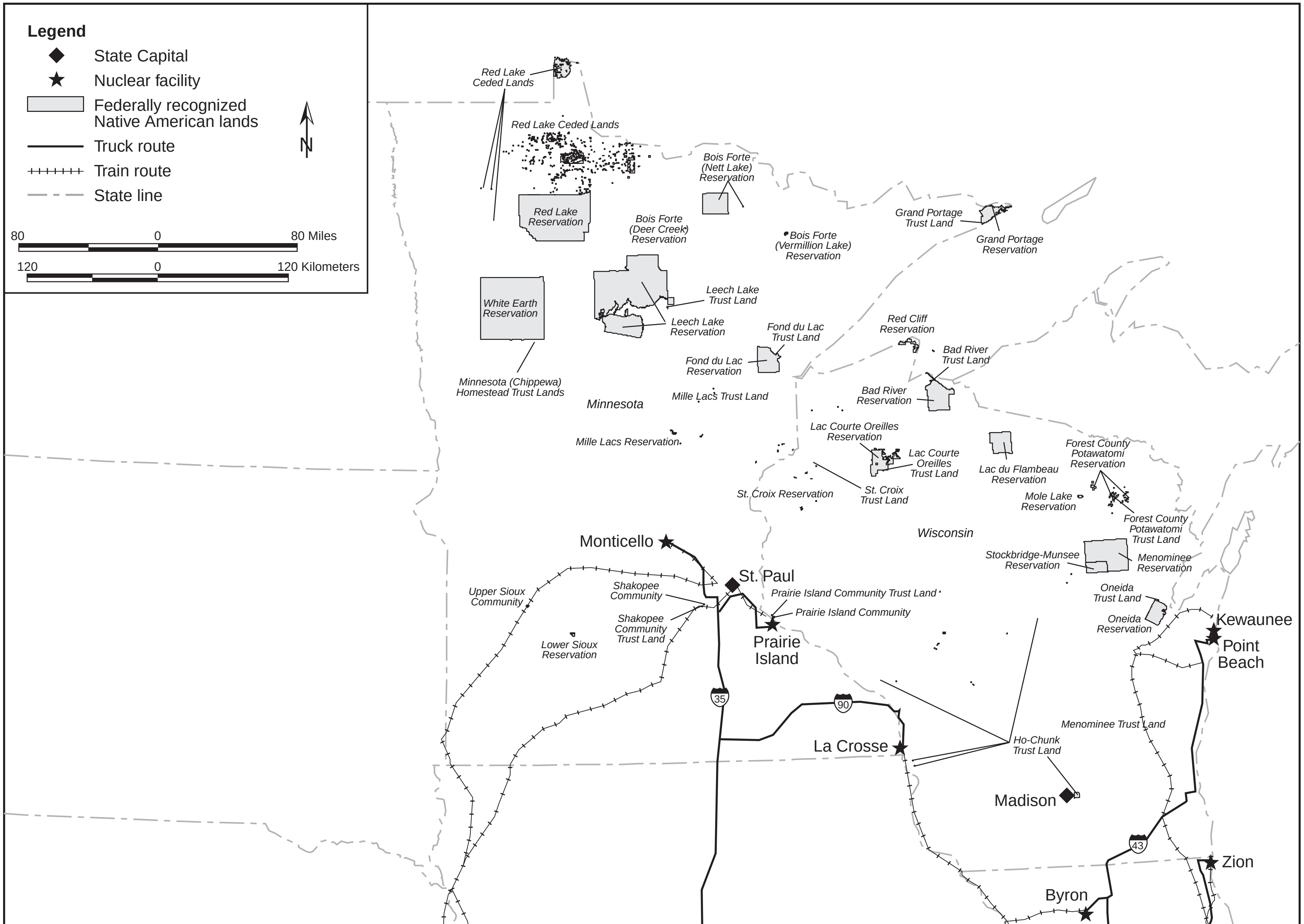
d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.



These routes represent the routes analyzed in Chapter 6 and might not be the routes actually used for shipments to the proposed repository at Yucca Mountain. Truck routes comply with U.S. Department of Transportation routing regulations. Rail routes are based on maximizing the distance on mainline track and minimizing the overall distance and number of interchanges between railroads.

Figure J-46. Highway and rail routes used to analyze transportation impacts - Minnesota and Wisconsin.

Table J-87. Estimated transportation impacts for the State of Missouri.

Impact category	Mostly legal-weight truck	Mostly rail: Ending rail node in Nevada[a]: Caliente[b]	Dry Lake[c]	Jean[d]	Beowawe[e]	Eccles[f]	Apex[g]
MISSOURI							
Shipments							
Truck (originating/total)	435/19,142	0/491	0/491	0/491	0/491	0/491	0/491
Rail (originating/total)	0/0	71/4,069	71/4,069	71/4,065	71/4,126	71/4,069	71/4,069
Radiological impacts							
Incident-free impacts							
Population (person-rem/LCFs)[h]	$3.5\times10^{2}/1.7\times10^{-1}$	$8.2\times10^{1}/4.1\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$	$7.8\times10^{1}/3.9\times10^{-2}$	$8.3\times10^{1}/4.2\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$	$8.2\times10^{1}/4.1\times10^{-2}$
Workers (person-rem/LCFs)	$7.5\times10^{2}/3.0\times10^{-1}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.6\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$	$1.4\times10^{2}/5.5\times10^{-2}$
Accident dose risk							
Population (person-rem/LCFs)	$4.8\times10^{-2}/2.4\times10^{-5}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.6\times10^{-2}/7.9\times10^{-6}$	$1.8\times10^{-2}/8.9\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$	$1.8\times10^{-2}/8.8\times10^{-6}$
Nonradiological impacts							
Vehicle emissions (LCFs)	7.5×10^{-2}	3.8×10^{-2}	3.8×10^{-2}	3.6×10^{-2}	3.8×10^{-2}	3.8×10^{-2}	3.8×10^{-2}
Fatalities	0.28	0.086	0.086	0.085	0.086	0.086	0.086

a. Under the mostly rail scenario, rail shipments would arrive in Nevada at one of six existing rail nodes. Impacts would vary according to the node. From that node, DOE would use one of the rail or heavy-haul implementing alternatives to complete the transportation to Yucca Mountain (see Section J.1.2).

b. For heavy-haul truck transportation, the Caliente junction is the location of the proposed Caliente intermodal transfer station for heavy-haul trucks near the town of Caliente in eastern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on one of the Caliente, Caliente/Chalk Mountain, or Caliente/Las Vegas routes. For branch rail line transportation, railcars would transfer via the Caliente Option to the Caliente Corridor at the Caliente junction.

c. For heavy-haul truck transportation, the Dry Lake junction is near the location of the proposed Apex/Dry Lake intermodal transfer station for heavy-haul trucks in southeast Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Apex/Dry Lake route.

d. For heavy-haul truck transportation, the Jean junction is near the location of the proposed Sloan/Jean intermodal transfer station for heavy-haul trucks in southern Nevada. Rail shipments terminating at this junction would continue to Yucca Mountain on heavy-haul trucks on the Sloan/Jean route. For branch rail line transportation, railcars would transfer from the mainline railroad via the Wilson Pass or Stateline Pass Option of the Jean Corridor, near the Jean junction.

e. For branch rail line transportation, railcars would transfer from the mainline railroad at the Beowawe junction in north-central Nevada to the Carlin Corridor.

f. For branch rail line transportation, railcars would transfer from the mainline railroad at the Eccles junction east of Caliente, Nevada, via the Eccles Option or nearby via the Crestline Option of the Caliente or Caliente-Chalk Mountain Corridor. Impacts in states outside Nevada would be the same for the Eccles and Crestline Options of the Caliente and Caliente-Chalk Mountain Corridors.

g. For branch rail line transportation, railcars would transfer from the mainline railroad at the Apex junction in southeast Nevada, possibly via the Valley Connection, to the Valley Modified Corridor.

h. LCF = latent cancer fatality.

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APPENDIX K. LONG-TERM RADIOLOGICAL IMPACT ANALYSIS FOR THE NO-ACTION ALTERNATIVE

K.1 Introduction

This appendix provides detailed information related to the radiological impact analysis for No-Action Alternative Scenario 2, including descriptions of the conceptual models used for facility degradation, spent nuclear fuel and high-level radioactive waste material degradation, and data input parameters. In addition, this appendix discusses the computer programs and exposure calculations used. The methods described include summaries of models and programs used for radioactive material release, environmental transport, radiation dose, and radiological human health impact assessment. Although the appendix describes No-Action Scenario 1, it focuses primarily on the long-term (100 to 10,000 years) radiological impacts associated with Scenario 2.

NO-ACTION ALTERNATIVE SCENARIOS 1 AND 2

Under the Nuclear Waste Policy Act, the Federal Government has the responsibility to provide permanent disposal of spent nuclear fuel and high-level radioactive waste to protect the public's health and safety and the environment. DOE intends to comply with the terms of existing consent orders and compliance agreements on the management of spent nuclear fuel and high-level radioactive waste. However, the course that Congress, DOE, and the commercial nuclear utilities would take if there was no recommendation to use Yucca Mountain as a repository is highly uncertain.

In light of these uncertainties, it would be speculative to attempt to predict precise consequences. To illustrate one set of possibilities, however, DOE decided to focus the analysis of the No-Action Alternative on the potential impacts of two scenarios:

Scenario 1: Long-term storage of spent nuclear fuel and high-level radioactive waste at the current storage sites, with effective institutional control for at least 10,000 years.

Scenario 2: Long-term storage of spent nuclear fuel and high-level radioactive waste, with the assumption of no effective institutional control after approximately 100 years.

DOE recognizes that neither of these scenarios is likely to occur if there was a decision to not develop a repository at Yucca Mountain. However, the Department selected these two scenarios for analysis because they provide a baseline for comparison to the impacts from the Proposed Action and because they reflect a range of the potential impacts that could occur.

To permit a comparison of the impacts between the construction, operation and monitoring, and eventual closure of a proposed repository at Yucca Mountain and No-Action Scenario 2, the U.S. Department of Energy (DOE) took care to maintain consistency, where possible, with the modeling techniques used to conduct the *Viability Assessment of a Repository at Yucca Mountain* (DIRS 101779-DOE 1998, all) and in the *Total System Performance Assessment – Viability Assessment (TSPA-VA) Analyses Technical Basis Document* (DIRS 100355, 100356, 100357, 100358, 100359, 100362, 100364, 100365, 100366, 100369, 100371-CRWMS M&O 1998, all) for the proposed repository (see Appendix I, Section I.1, for details). In pursuit of this goal, DOE structured this analysis to facilitate an impact comparison with the repository impact analysis. Important consistencies include the following:

- Identical evaluation periods (100 years and 10,000 years)

- Identical spent nuclear fuel and high-level radioactive waste inventories at the reference repository:
  - — Proposed Action: 63,000 metric tons of heavy metal (MTHM) of commercial spent nuclear fuel; 2,333 MTHM of DOE spent nuclear fuel; 8,315 canisters of high-level radioactive waste. This inventory includes an amount of surplus weapons-usable plutonium
  - — Module 1: All Proposed Action materials, plus an additional 42,000 MTHM of commercial spent nuclear fuel; 167 MTHM of DOE spent nuclear fuel; and 13,965 canisters of high-level radioactive waste. This would result in a total of approximately 105,000 MTHM of commercial spent nuclear fuel; 2,500 MTHM of DOE spent nuclear fuel; and 22,280 canisters of high-level radioactive waste. This inventory also includes the surplus weapons-usable plutonium (see Appendix A, Figure A-2)

DEFINITION OF
METRIC TONS OF HEAVY METAL

Quantities of spent nuclear fuel are traditionally expressed in terms of *metric tons of heavy metal* (typically uranium), without the inclusion of other materials such as cladding (the tubes containing the fuel) and structural materials. A metric ton is 1,000 kilograms (1.1 tons or 2,200 pounds). Uranium and other metals in spent nuclear fuel (such as thorium and plutonium) are called *heavy metals* because they are extremely dense; that is, they have high weights per unit volume. One metric ton of heavy metal disposed of as spent nuclear fuel would fill a space approximately the size of a typical household refrigerator.

- Consistent spent nuclear fuel and high-level radioactive waste corrosion and dissolution models
- Identical radiation dose and risk conversion factors
- Similar assumptions regarding the future habits and behaviors of population groups (that is, that they will not be much different from those of populations today)

Since issuing the Draft EIS, DOE has continued to evaluate design features and operating modes that would improve long-term repository performance and reduce uncertainty. The result of the design evolution process was the development of the flexible design (DIRS 153849-DOE 2001, all), which was evaluated in the Supplement to the Draft EIS. This design focuses on controlling the temperature of the rock between waste emplacement drifts. As a result of these design changes, this Final EIS evaluates a range of repository operating modes (higher- and lower-temperature). The lower-temperature operating mode has the flexibility to remain open and under active institutional control for up to 300 years after emplacement. Although Chapter 4 of this EIS includes an evaluation of impacts for this period, DOE did not evaluate the 300-year institutional control case for the No-Action Alternative. The primary reason for not updating this part of the analysis was because if the institutional control period for the analysis of the No-Action Alternative were extended to 300 years, the short-term environmental impacts would have increased by as much as 3 times. DOE did not want to appear to overstate the impacts from the No-Action Alternative.

Since the publication of the Draft EIS, DOE modified the spent nuclear fuel cladding corrosion rates and failure mechanisms used in the performance analysis in Chapter 5 of the Final EIS. DOE did not update these models for the No-Action Alternative Scenario 2 analysis because the outcome would have been an increase in the long-term radiation doses and potential health impacts, however, the increase would be within the uncertainties discussed in Section K.4. In addition, the radionuclide inventories for commercial spent nuclear fuel were updated for the Final EIS (see Appendix A, Tables A-8 and A-9) to reflect the higher initial enrichments and burnup projected for commercial nuclear facilities. Although these revised inventories were used to estimate potential short-term repository impacts in the Final EIS

(Chapter 4), DOE chose not to update the No-Action inventories because, again, the effect on the outcome would be about a 15-percent increase in health impacts in this chapter.

Affected populations for the No-Action Alternative were, in general, based on 1990 census estimates and not projected to 2035 as was done for the Proposed Action. However, if the population across the Nation had been projected to 2035, the collective impacts resulting from radiation exposure would have increased by less than a factor of 1.5, which is the average expected increase in national population from 1990 to 2035 (DIRS 152471-Bureau of the Census 2000, all).

For commercial facilities, the No-Action analysis estimated short- and long-term radiological impacts for Scenario 1 and short-term impacts for Scenario 2 during the first 100 years for facility workers and the public based on values provided by the U.S. Nuclear Regulatory Commission (DIRS 101898-NRC 1991, p. 21). For DOE facilities, radiological impacts for these periods under Scenarios 1 and 2 were estimated based on analysis by Orthen (DIRS 104596-Orthen 1999, all). To ensure consistency with the repository impact analysis, the long-term facility degradation and environmental releases of radioactive materials were estimated by adapting TSPA-VA process models developed to predict the behavior of spent nuclear fuel and high-level radioactive waste in the repository (DIRS 104597-Battelle 1998, pp. 2.4 to 2.9).

Because DOE did not want to influence the results to favor the repository, it used assumptions that generally resulted in lower predicted impacts (rather than applying the bounding assumptions used in many of the repository impact analyses) if TSPA-VA models were not available or not appropriate for this continuous storage analysis. For example, the No-Action Scenario 2 analysis took into account the protectiveness of the stainless-steel waste canister when estimating releases of radioactive material from the vitrified high-level radioactive waste; the TSPA-VA assumed no credit for material protection or radionuclide retardation by the intact canister. This approach dramatically reduced the release rate of high-level radioactive waste materials to the environment, thereby resulting in lower estimated total doses and dose rates to the exposed populations. Conversely, in many instances the TSPA-VA selected values for input parameters that defined ranges to ensure that there would be no underestimation of the associated impacts. Section K.4 discusses other consistencies and inconsistencies between the TSPA-VA and the No-Action analysis.

The long-term impact analysis used recent climate and meteorological data, assuming they would remain constant throughout the evaluation period (DIRS 101912-Poe and Wise 1998, all). DOE recognizes that there could be considerable changes in the climate over 10,000 years (precipitation patterns, ice ages, global warming, etc.) but, to simplify the analysis, did not attempt to quantify climate changes. Section K.4.1.2 discusses the difficulties of modeling these changes and the potential effect on outcomes resulting from uncertainties associated with predicting potential future climatic conditions.

Although the repository TSPA-VA used probabilistic process models to evaluate the transport of radioactive materials within Yucca Mountain and underlying groundwater aquifers, DOE used the deterministic computer program Multimedia Environmental Pollutant Assessment System (MEPAS; DIRS 101533-Buck et al. 1995, all) for the No-Action Scenario 2 analysis because of the need to model the transport of radioactive material. In addition, it discusses environmental pathways not present at the repository (for example, the movement of contaminants through surface water). The MEPAS program has been accepted and used by DOE and the Environmental Protection Agency for long-term performance assessments (DIRS 101917-Rollins 1998, pp. 1, 10, and 19).

K.2 Analytical Methods

This section describes the methodology used to evaluate the long-term degradation of the concrete facilities, steel storage containers, and spent nuclear fuel and high-level radioactive waste materials. In addition, it discusses the eventual release and transport of radioactive materials under Scenario 2. The

PROBABILISTIC AND DETERMINISTIC ANALYSES

A *probabilistic* analysis represents data input to a model as a range of values that represents the uncertainty associated with the actual or true value. The probabilistic model randomly samples these input parameter distributions many times to develop a possible range of results. The range of results provides a quantitative estimate of the uncertainty of the results.

A *deterministic* analysis uses a best estimate single value for each model input and produces a single result. The deterministic analysis will usually include a separate analysis that addresses the uncertainty associated with each input and provides an assessment of impact these uncertainties could have on the model results.

Analyses can use both approaches to provide similar information regarding the uncertainty of the results.

institutional control assumed under Scenario 1 would ensure ongoing maintenance, repair and replacement of storage facilities, and containment of spent nuclear fuel and high-level radioactive waste. For this reason, assuming the degradation of engineered barriers and the release and transport of radioactive materials is not appropriate for Scenario 1. The Scenario 2 analysis assumed that the degradation process would begin at the time when there was no effective institutional control (that is, after approximately 100 years) and the facilities would no longer be maintained. This section also describes the models and assumptions used to evaluate human exposures and potential health effects, and cost impacts.

K.2.1 GENERAL METHODOLOGY

For the No-Action analysis, the facilities, dry storage canisters, cladding, spent nuclear fuel, and high-level radioactive waste material, collectively known as the *engineered barrier system*, were modeled using an approach consistent (to the extent possible) with that developed for the Viability Assessment (DIRS 101779-DOE 1998, Volume 3). These process models were developed to evaluate, among other things, the performance of the repository engineered barrier system in the underground repository environment. In this analysis, the process models were adapted whenever feasible to evaluate surface environmental conditions at commercial and DOE sites. These models are described below.

Figure K-1 shows the modeling of the degradation of spent nuclear fuel and high-level radioactive waste and the release of radioactive materials over long periods. Five steps describe the process of spent nuclear fuel and high-level radioactive waste degradation; a sixth step, facility radioactive material release, describes the amount and rate of precipitation that would transport the radioactive material or *dissolution products* to the environment. This section describes each process and the results. Additional details are provided in reference documents (DIRS 101910-Poe 1998, all; DIRS 104597-Battelle 1998, all).

Environmental parameters important to the degradation processes include temperature, relative humidity, precipitation chemistry (pH and chemical composition), precipitation rates, number of rain-days, and freeze/thaw cycles. Other parameters considered in the degradation process describe the characteristics and behavior of the engineered barrier system, including barrier material composition and thickness. To simplify the analysis, the United States was divided into five regions (as shown in Figure K-2) for the purposes of estimating degradation rates and human health impacts (see Section K.2.1.6 for additional details).

Under the No-Action Alternative, commercial utilities would manage their spent nuclear fuel at 72 nuclear power generating facilities. DOE would manage its spent nuclear fuel and high-level radioactive waste at five DOE facilities [the Hanford Site (Region 5), the Idaho National Engineering and Environmental Laboratory (Region 5), Fort St. Vrain (Region 5), the West Valley Demonstration Project (Region 1), and the Savannah River Site (Region 2)]. The No-Action analysis evaluated DOE spent

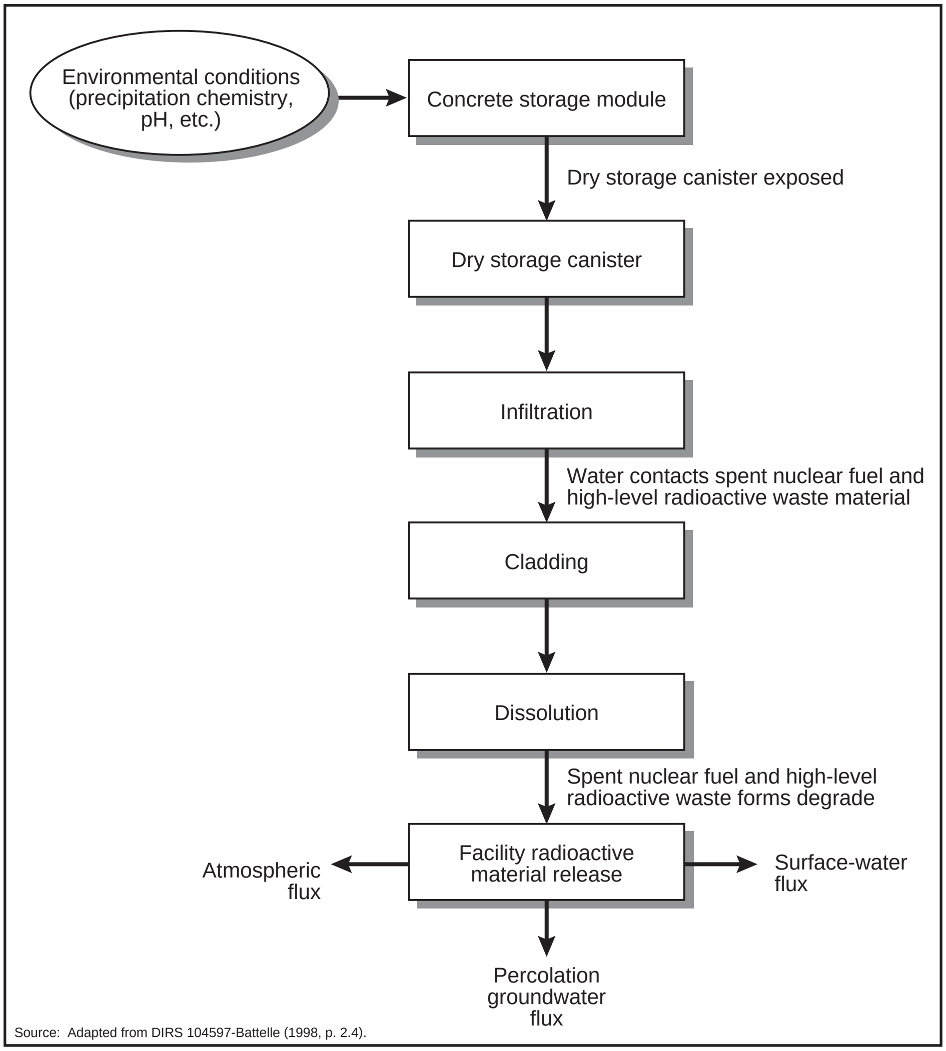


Figure K-1. Primary steps and processes involved in the degradation of the engineered barrier system.

nuclear fuel and high-level radioactive waste at the commercial and DOE sites or at locations where Records of Decision have placed or will place these materials (for example, West Valley Demonstration Project spent nuclear fuel was evaluated at the Idaho National Engineering and Environmental Laboratory (60 *FR* 28680, June 1, 1995). Therefore, the No-Action analysis evaluated DOE aluminum-clad spent nuclear fuel at the Savannah River Site and DOE non-aluminum-clad fuel at the Idaho National Engineering and Environmental Laboratory. DOE evaluated most of the Fort St. Vrain spent nuclear fuel at the Colorado site. In addition, the analysis evaluated high-level radioactive waste at the West Valley Demonstration Project, the Idaho National Engineering and Environmental Laboratory, the Hanford Site, and the Savannah River Site.

K.2.1.1 Concrete Storage Module Degradation

The first process model analyzed degradation mechanisms related to failure of the concrete storage module. *Failure* is defined as the time when precipitation would infiltrate the concrete and reach the spent nuclear fuel or high-level radioactive waste storage canister. The analysis (DIRS 101910-Poe 1998, Section 2.0) considered degradation due to exposure to the surrounding environment.

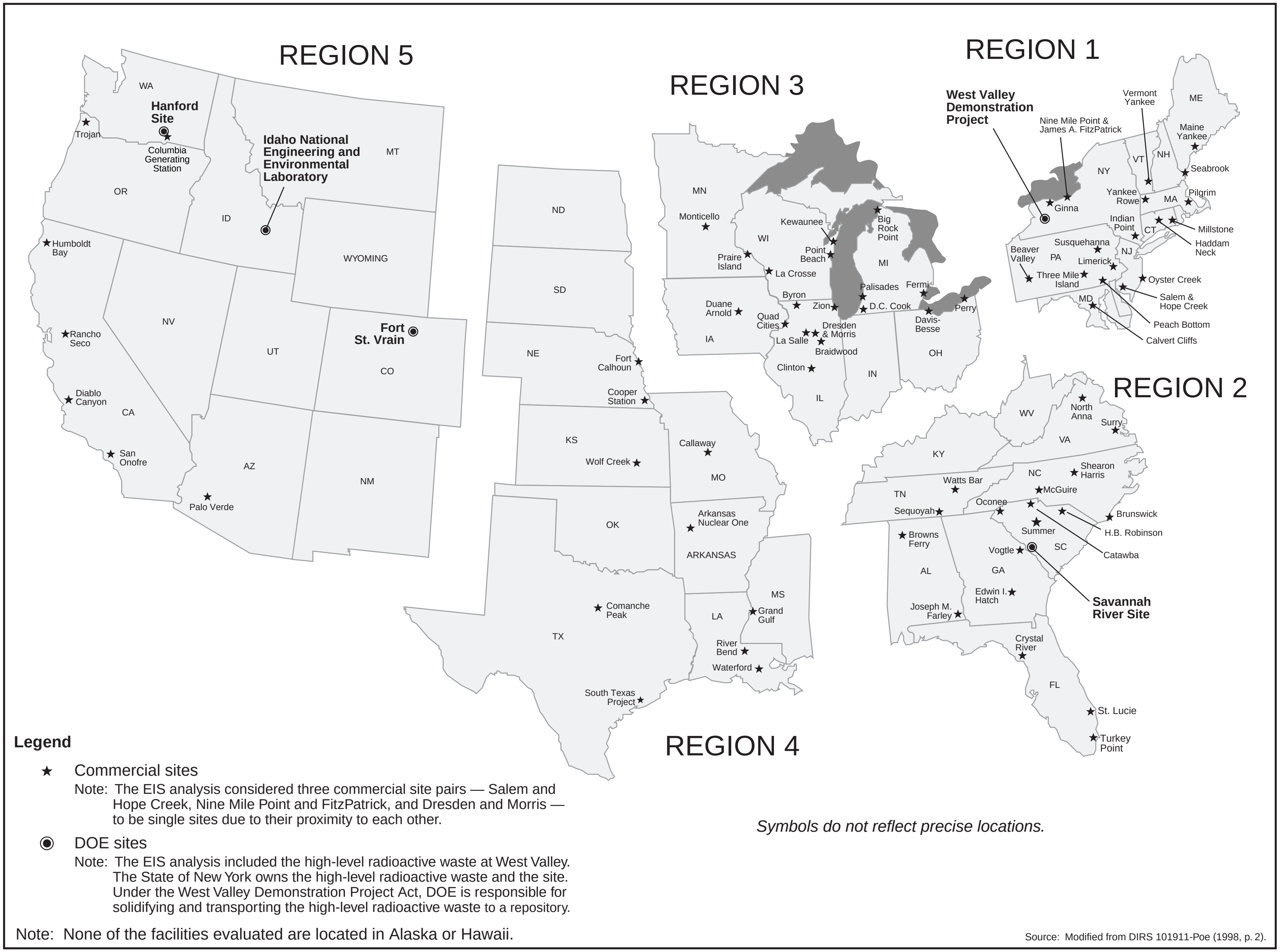


Figure K-2. No-Action Alternative analysis regions.

The primary cause of failure of surface-mounted concrete structures is freeze/thaw cycles that cause the concrete to crack and spall (break off in layers), which allows precipitation to enter the concrete, causing more freeze damage. *Freeze/thaw failure* is defined as the time when half of the thickness of the concrete is cracked and spalled. Some regions (coastal California, Texas, Florida, etc.) are essentially without the freeze/thaw cycle. In these locations the primary failure mechanism is precipitation containing chlorides, which decompose the chemical constituents of the concrete into sand-like materials. This process progresses more slowly than the freeze/thaw process. Figure K-3 shows estimated concrete storage module failure times.

Below-grade concrete structures, such as those used to store some of the DOE spent nuclear fuel and most of the high-level radioactive waste, would be affected by the same concrete degradation mechanisms as surface facilities. Below grade, the freeze/thaw degradation would not be as great because the soil would moderate temperature fluctuations. The primary failure mechanism for below-grade facilities would be the loss of the above-grade roof, which would result in precipitation seeping around shield plugs. The analysis assumed that this would occur 50 years after the end of facility maintenance, and that this would be the reasonable life expectancy of a facility without maintenance and periodic repair (DIRS 101910-Poe 1998, pp. 4-6 to 4-19).

K.2.1.2 Storage Canister Degradation

The second process analyzed was spent nuclear fuel and high-level radioactive waste storage canister degradation. For commercial and DOE spent nuclear fuel, the analysis defined failure of the stainless-steel dry storage canister as the time at which precipitation penetrated the canister and wet the spent nuclear fuel. The analysis defined failure for the high-level radioactive waste as the time at which precipitation penetrated the canisters. This is consistent with the repository definition that failure of the waste package would occur when water penetrated the package and came in contact with the contents. The stainless-steel model used for the No-Action analysis was consistent with the waste package inner layer corrosion model used for the repository TSPA-VA (DIRS 101779-DOE 1998, Volume 3, Section 3.4) with the functional parameters modified to incorporate stainless-steel corrosion data (Section K.4.3.1 discusses the sensitivity of outcome to carbon-steel dry storage containers). In addition, the analysis used parameters appropriate for above-ground conditions, including temperature, meteorological data, and chemical constituents in the atmosphere and precipitation. Although inconsistent with the assumptions used for the TSPA-VA, the analysis took credit for the protectiveness of the high-level radioactive waste canister because (1) it is the only container between the waste material and the environment and, (2) to ignore the protectiveness of this barrier would have resulted in a considerable overestimation of impacts. This approach is consistent with the decision, in the case of the No-Action Scenario 2 analysis, to provide a realistic radionuclide release rate where possible and to preclude the overestimation of the associated radiological human health impacts.

The primary determinants of stainless-steel corrosion for the different regions are the amount, the acidity, and the chloride concentration of the precipitation. The storage canisters degrade faster in the below-grade storage configuration than on the surface due to the higher humidity in the below-grade environment. The high-level radioactive waste canisters degrade faster than the spent nuclear fuel canisters because they are not as thick. The analysis evaluated three corrosion mechanisms—general corrosion, pitting corrosion, and crevice corrosion (DIRS 104597-Battelle 1998, Appendix A). Of the three, crevice corrosion would be the dominant failure mechanism for the regions analyzed. Corrosion rates and penetration times vary among the different regions of the country. The analysis calculated regional penetration times from the time at which it assumed that precipitation first would come in contact with the stainless steel. Table K-1 lists the results.

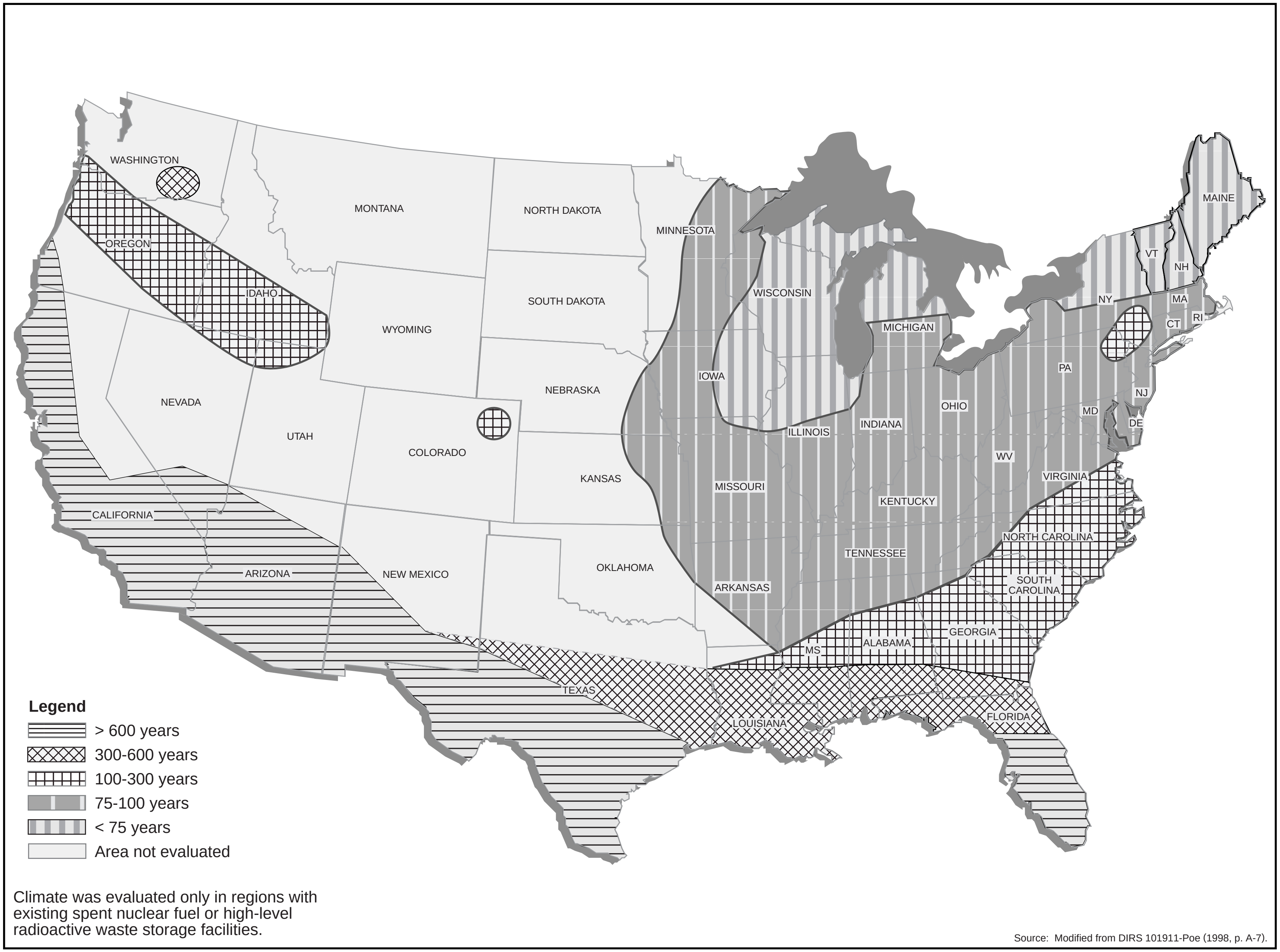


Figure K-3. Failure times for above-ground concrete storage modules.

Table K-1. Time (years) after the assumed loss of effective institutional control at which first failures would occur and radioactive materials could reach the accessible environment.

Material	Region	Storage facility	Weather[a] protection lost	Canister[b] breached (initial material release)
Commercial spent nuclear fuel	1	Surface	100	1,400
	2	Surface	700	1,500
	3	Surface	170	1,100
	4	Surface	750	1,600
	5	Surface	3,500	5,400
DOE spent nuclear fuel	2	Surface	700	1,400
	5	Surface	50	1,400
	5	Below grade	50	800
High-level radioactive waste	1	Surface	100	1,200
	2	Below grade	50	500
	5	Below grade	50	700

a. Source: Adapted from DIRS 101911-Poe (1998, Appendix A).
b. Source: DIRS 104597-Battelle (1998, data files, all); spent nuclear fuel dry storage or high-level radioactive waste canister.

K.2.1.3 Infiltration

The third process analyzes infiltration of water to the spent nuclear fuel and high-level radioactive waste. The amount of water in contact with these materials would be directly related to the size of the dry storage canister footprint and the mean (average) annual precipitation at each storage site. The rate of precipitation varies throughout the United States from extremely low (less than 25 centimeters [10 inches] per year) in the arid portions of the west to high (more than 150 centimeters [60 inches] per year) along the Gulf Coast in the southeast (Table K-2, Figure K-4). Local precipitation rates were used to determine the amount of water available that could cause dry storage canister and cladding failure, and spent nuclear fuel and high-level radioactive waste material dissolution.

Table K-2. Average regional precipitation.[a]

Region	Annual precipitation (centimeters)[b]	Percent of days with precipitation
1	110	30
2	130	29
3	80	33
4	110	31
5	30	24

a. Source: Adapted from DIRS 101911-Poe (1998, Appendix A, pp. A-13 to A-16).
b. To convert centimeters to inches, multiply by 0.3937.

K.2.1.4 Cladding

The fourth process analyzed was failure of the cladding, which is a protective barrier, usually metal (aluminum, zirconium alloy, stainless steel, nickel-chromium, Hastalloy, tantalum, or graphite), surrounding the spent nuclear fuel material to contain radioactive materials. For spent nuclear fuel, cladding is the last engineered barrier to be breached before the radioactive material can begin to be released to the environment.

K.2.1.4.1 *Commercial Spent Nuclear Fuel Cladding*

The principal cladding material used on commercial spent nuclear fuel is zirconium alloy. About 1.2 percent (of MTHM) of commercial spent nuclear fuel is stainless-steel clad (Appendix A,

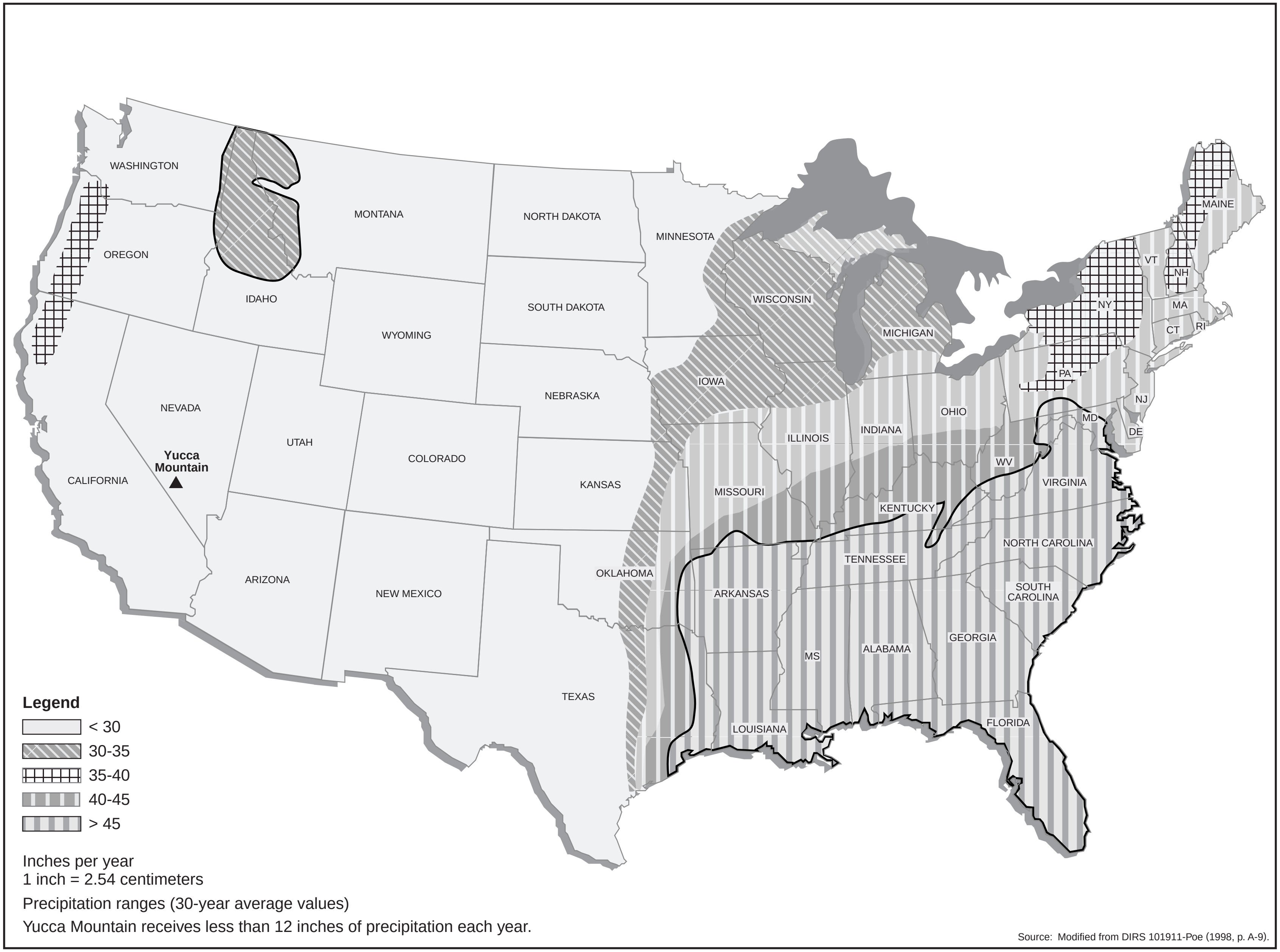


Figure K-4. Precipitation ranges for regions with existing spent nuclear fuel and high-level radioactive waste storage facilities.

Section A.2.1.5.3). To be consistent with the TSPA-VA, this analysis evaluated two cladding failure mechanisms: (1) so-called *juvenile failures* (failures existing at the start of the analysis period), and (2) *new failures* (failures that occur during the analysis period due to conditions in the storage container). The analysis assumed that juvenile failures existed in 0.1 percent of the zirconium alloy-clad spent nuclear fuel and in all of the stainless-steel-clad fuel at the beginning of the analysis period, and that after failure the cladding would offer no further protection to the radioactive material [this is consistent with the Viability Assessment assumption (DIRS 101779-DOE 1998, Volume 3, p. 3-97)].

Figure K-5 shows new failures (expressed as percent of commercial spent nuclear fuel over time) of zirconium alloy cladding, which were modeled using the median value assumed in the TSPA-VA cladding abstraction (DIRS 100362-CRWMS M&O 1998, pp. 6-19 to 6-54) for zirconium alloy corrosion. The Viability Assessment (DIRS 101779-DOE 1998, Volume 3, all) defines this information as a "fractional multiplier," which is calculated from the fraction of the failed fuel pin surface area. In the No-Action analysis, this corrosion is assumed to commence when weather protection afforded by the waste package is lost and the cladding is exposed to environmental precipitation. The TSPA-VA also considers cladding failure from creep strain, delayed hydride cracking, and mechanical failure from rock falls. These additional mechanisms normally occur after the 10,000-year analysis period and are therefore not considered in the No-Action analysis. As shown in Figure K-5, during the 10,000-year analysis period, less than 0.01 percent of the zirconium alloy-clad spent nuclear fuel would be expected to fail. If the upper limit curve from Figure 4 of the TSPA-VA cladding abstraction (DIRS 100362-CRWMS M&O 1998, pp. 6-19 to 6-54) was used, the value could be as high as 0.5 percent of the zirconium alloy-clad spent nuclear fuel. The lower limit value from the TSPA-VA cladding abstraction curve would be much less than 0.001 percent.

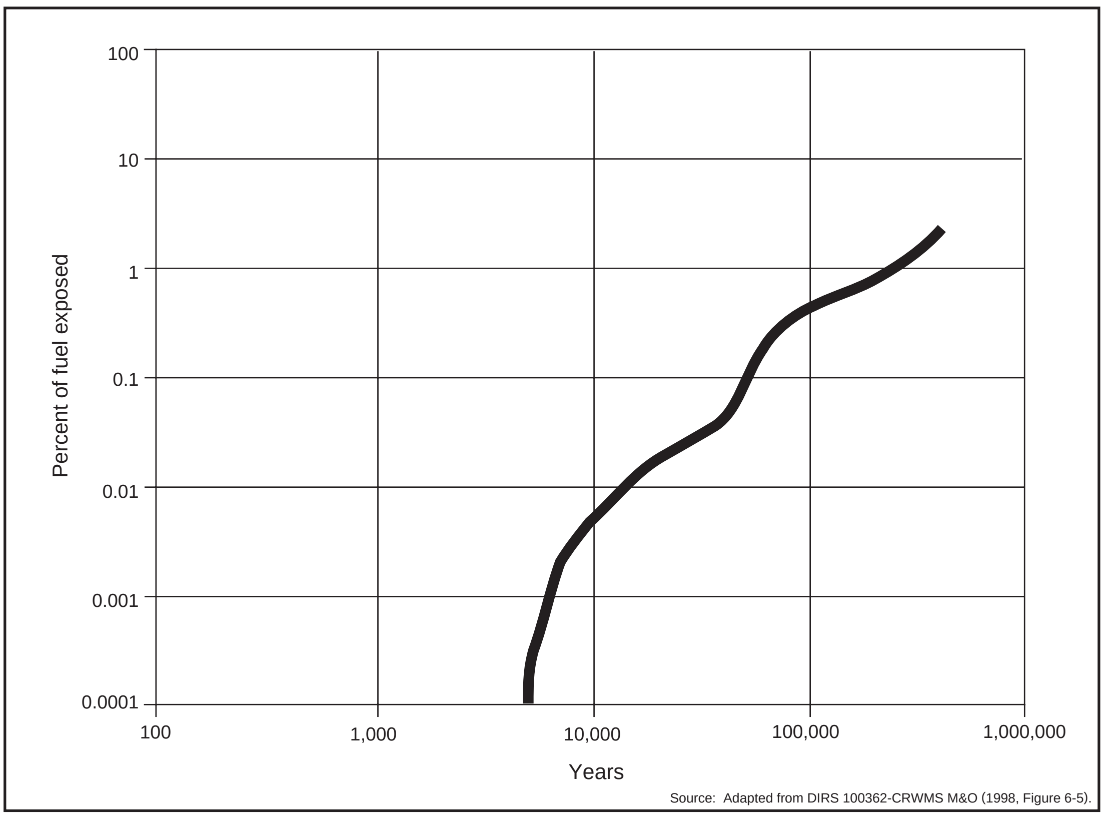


Figure K-5. Percent of commercial spent nuclear fuel exposed over time due to new failures.

K.2.1.4.2 *DOE Spent Nuclear Fuel Cladding*

The composition and cladding materials of DOE spent nuclear fuel vary widely. The cladding assumption for the surrogate material used in this analysis is identical (no cladding credit) to the assumption used in the TSPA-VA analysis (see Section K.4.3.1 for the discussion of uncertainty in relation to cladding).

K.2.1.5 Dissolution of Spent Nuclear Fuel and High-Level Radioactive Waste

The fifth process analyzed was the dissolution of the spent nuclear fuel and high-level radioactive waste. The rate of release of radionuclides from these materials would be related directly to the amount of surface area exposed to moisture, the quantity and chemistry of available water, and temperature. The TSPA-VA process model, modified to reflect surface environmental conditions (temperature, relative humidity, etc.), was used to estimate release rates from the exposed spent nuclear fuel and high-level radioactive waste. The model and application to surface conditions is described in detail in Battelle (DIRS 104597-Battelle 1998, pp. 2.9 to 2.11).

K.2.1.5.1 *Commercial Spent Nuclear Fuel Dissolution*

Consistent with the repository impact analysis, this analysis estimated that new zirconium alloy failures would begin late in the 10,000-year period (see Figure K-5). As discussed in Section K.2.1.4.1, only 0.01 percent of the zirconium alloy-clad spent nuclear fuel would be likely to fail during the 10,000-year analysis period. Therefore, most of the exposed material considered in this analysis would result from juvenile failures of zirconium alloy- and stainless-steel-clad spent nuclear fuel.

K.2.1.5.2 *DOE Spent Nuclear Fuel Dissolution*

The analysis assumed that DOE spent nuclear fuel would be a metallic uranium fuel with zirconium alloy cladding (a representative or surrogate fuel that consisted primarily of N-Reactor fuel). Consistent with the repository input analysis, the No-Action Scenario 2 analysis takes no credit for the cladding. The analysis used the TSPA-VA model for metallic uranium fuel, modified for surface environmental conditions, to predict releases of the DOE spent nuclear fuel.

K.2.1.5.3 *High-Level Radioactive Waste Dissolution*

Most high-level radioactive waste would be stored in below-grade concrete vaults. As discussed in Section K.2.1.1, these vaults would be exposed to precipitation as soon as weather protection was lost (the model assumed this would occur 50 years after loss of institutional control). After the loss of weather protection and failure of the stainless-steel canisters, the high-level radioactive waste would be exposed to precipitation. The environment in the underground vault would be humid and deterioration would occur. Thus, the material would be exposed to either standing water or humid conditions in the degrading vaults after the canister failed. The borosilicate glass deterioration model used in this analysis was the same as the TSPA-VA model modified to reflect surface conditions (temperature and precipitation chemistry).

K.2.1.6 Regionalization of Sites for Analysis

The climate of the contiguous United States varies considerably across the country. The release rate of the radionuclide inventory would depend primarily on the interactions between environmental conditions (rainfall, freeze-thaw cycles) and engineered barriers. To simplify the analysis, DOE divided the country into five regions (see Figure K-2) (DIRS 101911-Poe 1998, p. 2).

The analysis assumed that a single hypothetical site in each region would store all the spent nuclear fuel and high-level radioactive waste existing in that region. Such a site does not exist but is a mathematical construct for analytical purposes. To ensure that the calculated results for the regional analyses reflect appropriate inventory, facility and material degradation, and radionuclide transport, the spent nuclear fuel and high-level radioactive waste inventories, engineered barriers, and environmental conditions for the hypothetical sites were developed from data for each of the existing sites in the given region. Weighting criteria to account for the amount and types of spent nuclear fuel and high-level radioactive waste at each site were used in the development of the environmental data for the regional site, such that the results of the analyses for the hypothetical site were representative of the sum of the results of each actual site if they had been modeled independently (DIRS 101911-Poe 1998, p. 1). If there are no storage facilities in a particular area of the country, the environmental parameters of that area were not evaluated.

Table K-3 lists the Proposed Action and Module 1 quantities of commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste in each of the five regions. The values in Table K-1 are the calculated results of failures of the various components of the protective engineered barriers and release of radioactive material in each region.

Table K-3. Proposed Action and Module 1 quantities of spent nuclear fuel (metric tons of heavy metal) and canisters of high-level radioactive waste in each geographic region.[a,b]

	Commercial spent nuclear fuel[c]								
	Region total[d]		With juvenile cladding failure		Stainless-steel cladding	DOE spent nuclear fuel[e]		High-level radioactive waste[f]	
Region	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action and Module 1 (MTHM)	Proposed Action (MTHM)	Module 1 (MTHM)	Proposed Action[g] (canisters)	Module 1[g] (canisters)
1	16,800	27,000	16	27	410			300	300
2	18,900	31,800	19	32	0	30	45	6,000	6,200
3	15,000	22,900	15	23	170				
4	7,200	14,100	7	14	0				
5	5,400	9,600	5	9	140	2,300	2,455	2,000	15,500
Totals	***63,000***	***105,000***	***62***	***105***	***720***	***2,300***	***2,500***	***8,300***	***22,000***

a. Source: Appendix A.
b. Totals might differ from sums due to rounding.
c. All analyzed as stored on surface as shown on Chapter 2, Figures 2-32, 2-33, and 2-34.
d. Includes plutonium in mixed-oxide spent nuclear fuel, which is assumed to behave like other commercial spent nuclear fuel.
e. A representative or surrogate fuel that consisted primarily of N-reactor fuel.
f. Includes immobilized plutonium.
g. Historically, a canister of high-level radioactive waste has been assumed to be equivalent to about 0.5 MTHM (see Appendix A, Section A.2.3.1).

K.2.2 RADIONUCLIDE RELEASE

The sixth and final step in the process is the release of radioactive materials to the environment. The anticipated release rates (fluxes) were estimated in terms of grams per 70-year period (typical human life expectancy in the United States) of uranium dioxide, uranium metal, or borosilicate glass for commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste, respectively. To assess potential lifetime impacts on human receptors, the amount of fission products and transuranics associated with gram quantities of uranium dioxide, uranium metal, and borosilicate glass were calculated for approximately 140 consecutive 70-year average human lifetimes to determine releases from the 10,000-year analysis period. Weighting criteria were used to ensure appropriate contributions by the different types of spent nuclear fuel and the high-level radioactive waste in each region, as appropriate.

The result was a single release rate for each region that accounted for the different materials (uranium dioxide, uranium metal, and borosilicate glass).

The radionuclide distributions in the spent nuclear fuel and high-level radioactive waste (Appendix A) were used for these analyses. These were expressed as radionuclide-specific curies for storage packages (assembly or canister). The curies per storage package were converted to curies per gram of uranium dioxide, uranium metal, or borosilicate glass (as described above for each spent nuclear fuel and high-level radioactive waste material). This radionuclide distribution was multiplied by release flux (curies of spent nuclear fuel and high-level radioactive waste material per 70-year period) after being corrected for decay and the ingrowth of decay products for various times after disposal. These corrections were determined using the ORIGEN computer program (DIRS 147923-RSIC 1991, all) for each of the approximately 140 consecutive 70-year human lifetimes to determine the release over the 10,000-year period. The results of the ORIGEN runs were used as input to the environmental transport program.

DEFINITIONS

Fission products: Radioactive or non-radioactive atoms that are produced by the fission (splitting) of heavy atoms, such as uranium.

Transuranics: Radioactive elements, heavier than uranium, that are produced in a nuclear reactor when uranium atoms absorb neutrons rather than splitting. Examples of transuranics include plutonium, americium, and neptunium.

Curie: The basic unit of radioactivity. It is equal to the quantity of any radionuclide in which 37 billion atoms are decaying per second.

Specific activity: An expression of the number of curies of activity per gram of a given radionuclide. It is dependent on the half life and molecular weight of the nuclide.

In addition to the isotopes identified in the repository inventory specified in Appendix A, the No-Action Scenario 2 analysis considered 167 other isotopes in the light-water reactor radiological database (DIRS 102588-DOE 1992, p. 1.1-1). Of the 220 isotopes evaluated, six would contribute more than 99.5 percent of the total dose. Table K-4 lists these six isotopes along with technetium-99, which individually would contribute less than 0.003 percent of the total dose. Plutonium-239 and -240 would contribute more than 96 percent of the radiological impacts during the 10,000-year analysis period because of their very large dose conversion factors. Americium-241 and -243 would be minor contributors to the dose. Neptunium-237 and technetium-99 were of tertiary importance (Table K-4).

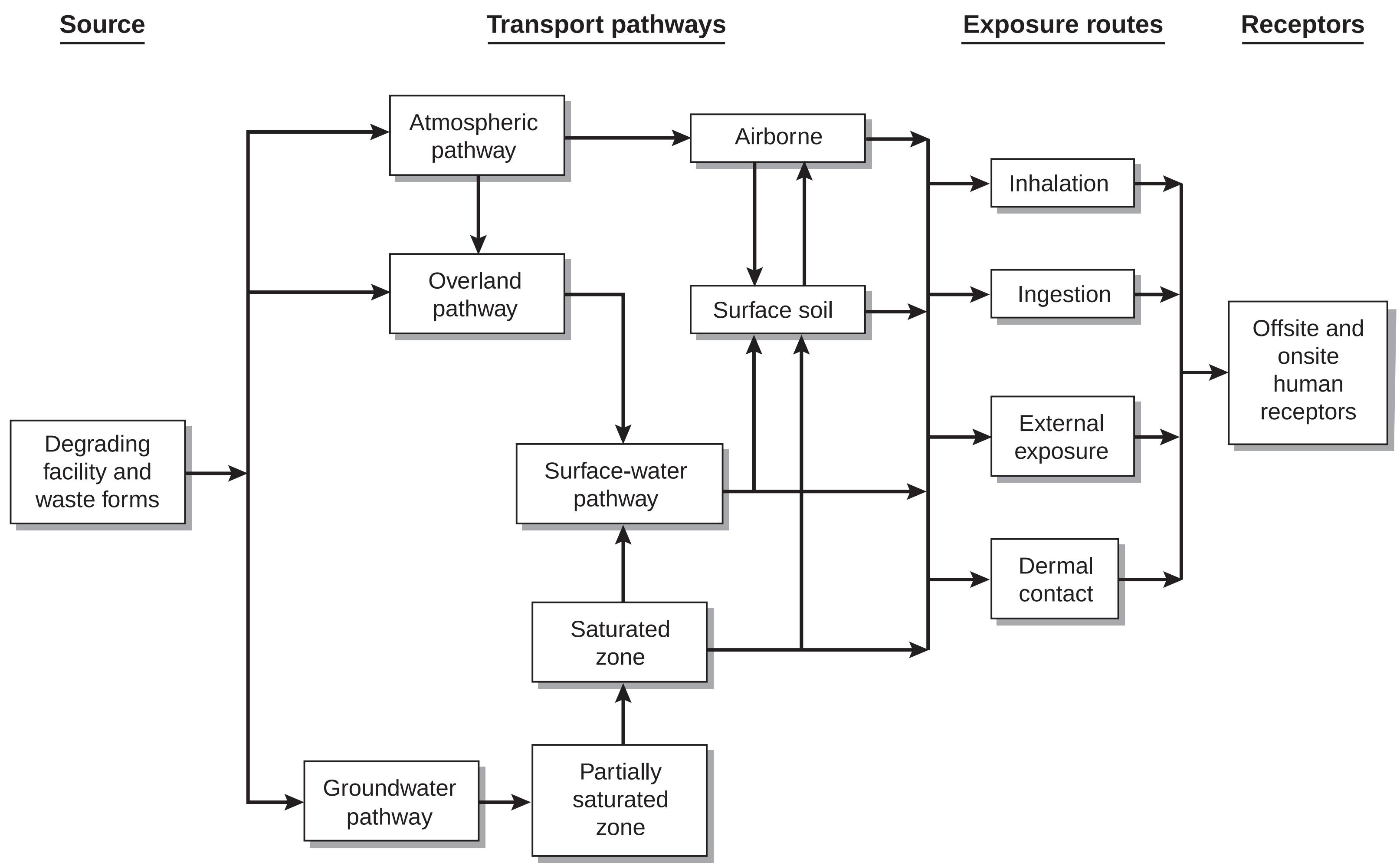
Table K-4. Radionuclides and relative contributions over 10,000 years to Scenario 2 impacts.[a]

Isotope	Percent of total dose
Americium-241	3.2
Americium-243	0.86
Neptunium-237	0.29
Plutonium-238	0.2
Plutonium-239	49.0
Plutonium-240	47.0
Technetium-99	< 0.003

a. Source: DIRS 101935-Toblin (1999, p. 6).

K.2.3 ENVIRONMENTAL TRANSPORT OF RADIOACTIVE MATERIALS

Radioactive materials in degraded spent nuclear fuel and high-level radioactive waste could be transported to the environment surrounding each storage facility by three pathways: groundwater, surface-water runoff, and atmosphere. Figure K-6 shows the potential exposure pathways. The analysisassumed that existing local climates would persist throughout the time of exposure of the spent nuclear fuel and high-level radioactive waste to the environment. The assumed configuration for the



Source: Adapted from DIRS 101533-Buck et al. (1995, all).

Figure K-6. Potential exposure pathways associated with degradation of spent nuclear fuel and high-level radioactive waste.

degraded storage facilities would have debris covering the radioactive material, which would remain inside the dry storage canisters. While the dry storage canisters could fail sufficiently to permit water to enter, they probably would retain their structural characteristics, thereby minimizing the dispersion of radioactive particulate material to the atmosphere (DIRS 147905-Mishima 1998, p. 4). Based on this analysis, the airborne particulate pathway generally would not be an important source of human exposure. The assumption is that after radionuclides dissolved in the precipitation they would reach the environment either through groundwater or surface-water transport.

The analysis performed environmental fate and transport pathway modeling using the Multimedia Environmental Pollutant Assessment System program (DIRS 101533-Buck et al. 1995, all). The Multimedia Environmental Pollutant Assessment System is an integrated system of analytical, semianalytical, and empirically based mathematical models that simulate the transport and fate of radioactive materials through various environmental media and calculate concentrations, doses, and health effects at designated receptor locations.

The Multimedia Environmental Pollutant Assessment System was originally developed by Pacific Northwest National Laboratory to enable DOE to prioritize the investigation and remediation of the Department's hazardous, radioactive, and mixed waste sites in a scientific and objective manner based on readily available site information. The Multimedia Environmental Pollutant Assessment System has evolved into a widely accepted (by Federal and international agencies) computational tool for calculating the magnitude of environmental concentrations and public health impacts caused by releases of radioactive material from various sources.

The following sections discuss the assumptions and methods used to determine radioactive material transport for groundwater and surface-water pathways. Environmental parameters defined for input to the Multimedia Environmental Pollutant Assessment System program were collected from various sources for specific sites (DIRS 101925-Sinkowski 1998, p. 2) and regionalized parameters were developed (DIRS 101912-Poe and Wise 1998, all). The analysis used long-term averages to represent environmental conditions, and assumed that these parameters would remain constant over the 10,000-year analysis period. The following sections discuss the method for each pathway.

K.2.3.1 Groundwater Transport

Precipitation falling on degrading spent nuclear fuel and high-level radioactive waste material would form a radioactive solution (leachate) that could migrate through the vadose zone (the unsaturated upper layer of soil) to the underlying water table, which would dilute, disperse, and transport the material downgradient through the local aquifer system. As a result, there is a potential for human exposure through the groundwater pathway to downgradient well users and to populations along surface-water bodies where groundwater feeds into surface water.

The groundwater component of the radioactive material fluxes (infiltration) averaged over 70-year (lifetime) increments was entered in the Multimedia Environmental Pollutant Assessment System program. The infiltration would carry the contaminated leachate down through the vadose zone to the saturated zone (aquifer). The contaminants would be diluted and dispersed as they traveled through the aquifer. Radioactive material retardation would occur in both the unsaturated (above the water table) and saturated (below the water table) zones. A distribution adsorption (that is, surface retention) coefficient, K_d, (the amount of material adsorbed to soil particles relative to that in the water) modeled this retardation (DIRS 101935-Toblin 1999, p. 2). This coefficient is radioactive material-specific and varies for each material based on such factors as soil pH and clay content.

Table K-5 lists the adsorption coefficients, K_d, for the elements explicitly modeled for groundwater transport. The coefficients are expressed as a function of the clay content of the soil through which the

Table K-5. Multimedia Environmental Pollutant Assessment System default elemental equilibrium adsorption coefficients (K_d; milliliters per gram) for soil pH between 5 and 9.[a]

Element	Clay content by weight		
	< 10 percent	10 to 30 percent	≥ 30 percent
Actinium	228	538	4,600
Americium	82	200	1,000
Californium	0	0	0
Carbon	0	0	0
Cesium	51	249	270
Chlorine	0	0	0
Cobalt	2	9	200
Curium	82	200	1,000
Iodine	0	0	0
Krypton	0	0	0
Lead	234	597	1,830
Neptunium	3	3	3
Nickel	12	59	650
Niobium	50	100	100
Palladium	0	4	40
Plutonium	10	100	250
Protactinium	0	50	500
Radium	24	100	124
Ruthenium	274	351	690
Samarium	228	538	4,600
Selenium	6	15	15
Strontium	24	100	124
Technetium	3	20	20
Thorium	100	500	2,700
Tin	5	10	10
Tritium	0	0	0
Uranium	0	50	500
Zirconium	50	500	1,000

a. Source: DIRS 101935-Toblin (1999, p. 2).

elements are being transported; the analyses assumed a soil pH between 5 and 9. Note that the K_d values of all isotopes of a given element (for example, plutonium-238, -239, and -240) are the same, because adsorption is a chemical rather than nuclear process.

The time required to traverse the groundwater was determined for each radionuclide. Tables K-6 and K-7 list the range of nuclide groundwater transport times, from source to receptor, for each of the five regions. Times are listed for the important nuclides (see Table K-4). The analysis assumed that the vadose/aquifer flow fields were steady-state, so that the nuclide travel times at a particular site would be constant over the 10,000-year analysis period, although the nuclide release rates were not. Table K-6 lists parameters describing the total (over the analysis period) and maximum nuclide release rates for the same important nuclides. Region 5, dominated by two large DOE sites, is seen to result in the largest nuclide releases of all of the regions.

Table K-7 also lists the number of water systems and people that would obtain water from the affected waterways. Many of these people would be subject to impacts from more than one site because they would obtain their water from affected waterways downstream from multiple sites.

When the groundwater reached the point where it outcropped to surface water, radioactive material transport would be subject to further dilution and dispersion. For most of the regions analyzed, the

Table K-6. Regional source terms and environmental transport data for important isotopes used for collective drinking water radiological impact analysis.[a]

Parameter	Plutonium-239/240	Plutonium-238	Americium-241	Americium-243	Neptunium-237	Technetium-99
Nuclide released in 10,000 years (curies)						
Region 1	4,200	20	660	115	8.9	98
Region 2	17,000	97	1,500	240	32	1,200
Region 3	130,000	660	31,000	3,300	260	2,600
Region 4	4,300	17	450	110	9.0	89
Region 5	570,000	180	42,000	1,700	720	6,500
Maximum annual nuclide release (curies per year)						
Region 1	19	0.020	1.2	0.053	0.0031	0.034
Region 2	53	0.035	2.2	0.11	0.0083	0.19
Region 3	60	0.71	56	1.6	0.092	1.0
Region 4	0.20	0.016	0.78	0.054	0.0034	0.035
Region 5	140	0.22	66	0.47	0.14	1.4
Years (from 2016) of maximum annual nuclide release						
Region 1	1,435	1,435	1,435	1,435	1,435	1,435
Region 2	1,575	1,575	1,575	1,575	1,575	1,575
Region 3	1,155	1,155	1,155	1,155	1,155	1,155
Region 4	1,715	1,715	1,715	1,715	1,715	1,715
Region 5	875	875	875	875	875	875
Nuclide reaching receptors in 10,000 year (curies)						
Region 1	3,600	11	130	43	8.8	95
Region 2	13,000	10	1.4	39	31	1,100
Region 3	110,000	250	380	510	250	2,500
Region 4	2,000	3.6	0.66	24	6.0	59
Region 5	180,000	2.6	0.020	1.2	630	5,600
Nuclide transport time[b] (years)						
Region 1	10-5,500	10-5,500	10-45,000	10-45,000	10-1,700	10-1,700
Region 2	460-9,000	460-9,000	2,000-36,000	2,000-36,000	43-860	140-1,500
Region 3	65-45,000	65-45,000	410-260,000	410-260,000	31-9,800	31-9,800
Region 4	850-520,000	850-520,000	3,000-1,000,000	3,000-1,000,000	59-16,000	130-100,000
Region 5	1,400-26,000	1,400-26,000	2,700-220,000	2,700-220,000	44-8,000	280-8,000

a. Source: DIRS 101935-Toblin (1999, p. 4).
b. Time from source to receptor.

Table K-7. Transport and population data for drinking water pathway impact analysis.

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Groundwater flow time (years)[a]	2.0 - 59	4.6 - 37	1.8 - 420	4.6 - 960	2.9 - 190
Number of people that would obtain domestic water supply from affected waterways (millions)[b]	6.7	5.3	13.1	5.3	0.16
Affected drinking water systems[c]	112	147	137	64	23

a. From source to outcrop; Source: Adapted from DIRS 101852-Jenkins (1998, Table 2).
b. Source: DIRS 101911-Poe (1998, p. 12).
c. Source: Adapted from DIRS 101925-Sinkowski (1998, all).

distance between the storage location and the downgradient surface-water body would be inside the site boundary; therefore, offsite wells generally would not be affected. However, the analysis calculated groundwater concentrations for hypothetical onsite and offsite receptors. The Multimedia Environmental Pollutant Assessment System program calculated groundwater and surface-water concentrations at each receptor location for consecutive 70-year lifetimes in the 10,000-year analysis period.

The parameters necessary for the spent nuclear fuel and high-level radioactive waste storage sites for the Multimedia Environmental Pollutant Assessment System were defined. Pertinent hydrologic and hydrogeologic information was derived from the site-specific Updated Final Safety Analysis Reports for commercial nuclear sites and site-specific data provided by the various DOE sites (DIRS 101852-Jenkins 1998, p. 1).

Table K-8 lists the range (over the individual sites) in each region of the important hydrogeologic parameters that would affect the transport of the radionuclides through the groundwater. These parameters form the basis for the nuclide transport times listed in Table K-7.

Table K-8. Multimedia Environmental Pollutant Assessment System regional groundwater input parameters.[a]

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Vadose zone					
Contaminated liquid infiltration rate (vertical Darcy velocity) (feet per year)[b]	3.1 - 3.5	4.4	2.7 - 3.1	2.7 - 4.4	0.88 - 3.1
Clay content (percent)	0 - 15	1 - 47	1 - 47	3 - 15	0 - 15
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	6 - 40	5 - 70	4 - 31	5 - 50	23 - 250
Bulk density (grams per cubic centimeter)	1.4 - 1.9	1.4 - 1.6	1.4 - 1.6	1.4 - 1.6	1.4 - 1.7
Total porosity (percent)	5 - 46	38 - 49	38 - 49	38 - 46	38 - 49
Field capacity (percent)	2.5 - 28	9 - 42	9 - 42	9 - 28	3 - 28
Saturated hydraulic conductivity (feet per year)	210 - 6,800	27 - 6,800	27 - 6,800	210 - 6,800	72 - 6,800
Aquifer					
Clay content (percent)	0 - 10	0 - 47	0 - 15	0 - 15	0 - 10
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	6 - 120	10 - 85	7 - 160	20 - 150	25 - 250
Bulk density (grams per cubic centimeter)	1.6 - 2.1	1.4 - 2.0	1.5 - 1.7	1.4 - 1.7	1.5 - 1.9
Total porosity (percent)	5 - 44	5 - 49	5 - 46	5 - 46	23 - 44
Effective porosity (percent)	2.9 - 22	2.9 - 28	2.9 - 25	22 - 27	13 - 25
Saturated hydraulic conductivity (feet per year)	210 - 6,800	27 - 6,800	27 - 6,800	210 - 6,800	72 - 6,800
Darcy velocity (feet per year)	6.8 - 1,400	12 - 170	3.9 - 430	0.58 - 270	33 - 560
Travel distance (feet)	1,900 - 5,600	2,000 - 4,700	1,900 - 23,000	1,600 - 12,000	1,900 - 37,000

a. Source: Adapted from DIRS 101852-Jenkins (1998, Table 2).
b. Annual precipitation rate (through degraded structure).

A simplifying analytical assumption was that radioactive material transport would occur only through the shallowest aquifer beneath the site. Because this assumption limits the interchange of groundwater with underlying aquifers, less radioactive material dilution would occur, and groundwater pathway impacts could be slightly overestimated. However, because impacts from the groundwater pathway would be minor in comparison to surface-water pathways, the total estimated impacts would not be affected by this assumption.

K.2.3.2 Surface-Water Transport

The amount of leachate from degraded spent nuclear fuel and high-level radioactive waste in the surface-water pathway would depend on soil characteristics and the local climate. The Multimedia Environmental Pollutant Assessment System considers precipitation rates (Table K-2), soil infiltration, evapotranspiration, and erosion management practices to determine the amount of leachate that would run off rather than percolate into the soil. The contaminated runoff would travel overland and eventually enter nearby rivers and streams that would dilute it further.

To determine the impacts of the contaminated discharge to surface water on the downstream populations using that water (affected populations), DOE calculated the surface water flow rate and the release rate of contaminants (as curies per year) contributed by each storage location draining to the surface water. Using these values, DOE determined surface-water radionuclide concentrations for each receptor location. DOE applied these concentrations to the respective affected populations to estimate impacts for each region.

K.2.3.3 Atmospheric Transport

If degraded spent nuclear fuel or high-level radioactive waste was exposed to the environment, small particles could become suspended in the air and transported by wind. The Multimedia Environmental Pollutant Assessment System methodology includes formulations for radioactive material (particulate) suspension by wind, vehicular traffic, and other physical disturbances of the ground surface. The impacts from the atmospheric pathways would be small in comparison to surface-water pathways because the cover provided by the degraded structures and the relatively large particle size and density of the materials (see Section K.2.3) would preclude suspension by wind. Therefore, impacts from the transport of radioactive particulate materials were not included in the analysis.

K.2.4 HUMAN EXPOSURE AND DOSE CALCULATIONS

This section describes methods used in the No-Action Scenario 2 analysis to estimate dose rates and potential impacts to individuals and population groups from exposures to radionuclide contaminants in groundwater and surface water and in the atmosphere. As discussed above, these contaminated environmental media would result from the degradation of storage facilities (Sections K.2.1.1), corroding dry storage canisters (Section K.2.1.2), cladding failure (Section K.2.1.4), spent nuclear fuel and high-level radioactive waste dissolution (Section K.2.1.5), leachate percolation and groundwater transport (Section K.2.3.1), surface-water runoff (Section K.2.3.2), and atmospheric suspension and transport (Section K.2.3.3).

For Scenario 1 and the first 100 years of Scenario 2, the presence of effective institutional control would ensure that radiological releases to the environment and radiation doses to workers and the public remained within Federal limits and DOE Order requirements and were maintained as low as reasonably achievable. As a result, impacts to members of the public would be very small. Potential radiological human health impacts that could occur would be due primarily to occupational radiation exposure of onsite workers. The analysts estimated these impacts based on actual operational data from commercial nuclear powerplant sites (DIRS 101898-NRC 1991, pp. 22 to 25) and projected these impacts for the 100- and 10,000-year analysis periods for Scenario 1.

For Scenario 2, impacts to onsite workers and the public during institutional control (approximately 100 years) would be the same as those for Scenario 1. However, because the assumption for Scenario 2 is that there would be no effective institutional control after approximately 100 years, engineered barriers would begin to degrade and eventually would not prevent radioactive materials from the spent nuclear fuel and high-level radioactive waste from entering the environment. During the period of no effective institutional control, there would be no workers at the site. Thus, impacts were calculated only for the public.

For Scenario 2, the potential highest exposures and dose rates over a 70-year lifetime period were evaluated for individuals and exposed populations. In addition, the total integrated dose to the exposed population for the 10,000-year analysis period was estimated. Human exposure parameters (exposure times, ingestion and inhalation rates, agricultural activities, food consumption rates, etc.) were developed based on recommendations from Federal agencies (DIRS 101819-EPA 1988, pp. 113 to 131; DIRS 101820-EPA 1991, Attachment B; DIRS 100067-NRC 1977, pp. 1.109-1 to 1.109-2; DIRS 147925-

Shipers and Harlan 1989, all; DIRS 147915-NRC 1991, Chapter 6) and are reflected as Multimedia Environmental Pollutant Assessment System default values (DIRS 101533-Buck et al. 1995, Section 1.0). Other parameters chosen for this analysis are summarized in supporting documentation (DIRS 101925-Sinkowski 1998, all; DIRS 101935-Toblin 1999, all; DIRS 101936-Toblin 1999, all; DIRS 101937-Toblin 1998, all). Table K-9 lists the exposure and usage parameters for all of the pathways considered in the analysis (see Section K.3.1).

The Scenario 2 analysis evaluated long-term radiation doses and impacts to populations exposed through the surface-water and groundwater pathways. This analysis estimated population impacts only for the drinking water pathway using regionalized effective populations and surface-water dilution factors discussed in Section K.2.3.2. Other pathways were evaluated to determine their potential contribution in relation to drinking water doses. These analyses are discussed in Section K.3.1.

K.2.4.1 Gardener Impacts

To reasonably bound human health impacts resulting from human intrusion, two types of gardener were evaluated—the onsite gardener (10 meters [33 feet]) from the degrading storage facility) and the near-site gardener (5 kilometers [3 miles] from the degrading facility). The analysis had both of these hypothetical gardeners residing on the flow path for groundwater. The gardeners would obtain all their drinking water from contaminated groundwater, grow their subsistence gardens in contaminated soils, and irrigate them with the contaminated groundwater. The contaminated garden soils, suspended by the wind, would contaminate the surfaces of the vegetables consumed by the gardeners. The hypothetical onsite gardener would be the maximally exposed individual.

HUMAN INTRUSION

Spent nuclear fuel and high-level radioactive waste in surface or below-grade storage facilities would be readily accessible in the absence of institutional control. For this reason, DOE anticipates that both planned and inadvertent intrusions could occur. An example of the former would be the scavenger who searches through the area seeking articles of value; an example of the latter would be the farmer who settles on the site and grows agricultural crops with no knowledge of the storage structure beneath the soil. Intrusions into contaminated areas also could occur through activities such as building excavations, road construction, and pipeline or utility replacement.

Under the conditions of Scenario 2, intruders could receive external exposures from stored spent nuclear fuel and high-level radioactive waste that would grossly exceed current regulatory limits and, in some cases, could be sufficiently high to cause prompt fatalities. In addition, long-term and repeated intrusions, such as those caused by residential construction or agricultural activities near storage sites, could result in long-term chronic exposures that could produce increased numbers of latent cancer fatalities. These intrusions could also result in the spread of contamination to remote locations, which could increase the total number of individuals potentially exposed.

Calculations were performed using transport models described by DIRS 101533-Buck et al. (1995, all) for gardeners in each of the five analysis regions using regionalized source terms and environmental parameters. Therefore, calculated impacts to the regional gardener (maximally exposed individual) would not represent the highest impacts possible from a single site in a given region, but rather would reflect an average impact for the region. Details of the analysis are provided in DIRS 101937-Toblin (1998, all). The regional hydrogeologic parameters listed in Table K-10, together with transient nuclide release rates (the maximum of which is indicated in the table), were used to determine the radiological impacts to the regional gardener as a result of groundwater transport. The regional parameters were based on a curie-weighting of the individual site parameters for plutonium and americium. The exposure

Table K-9. Multimedia Environmental Pollutant Assessment System human exposure input parameters for determination of all pathways radiological impacts sensitivity analysis (page 1 of 2).[a]

Water source[b]	Surface water
Domestic water supply treatment[c]	Yes
Fraction of plutonium removed by water treatment[d]	0.3
Drinking water rate (liters per day per person)[e]	2
Irrigation rate (liters per square meter per month)[f]	100
Leafy vegetable consumption rate (kilograms per day per person)[g]	0.021
Other vegetable consumption rate (kilograms per day per person)	0.13
Meat consumption rate (kilograms per day per person)	0.065
Milk consumption rate (kilograms per day per person)	0.075
Finfish consumption rate (kilograms per day per person)	0.0065
Shellfish consumption rate (kilograms per day per person)	0.0027
Shoreline contact (hours per day per person)	0.033
Americium ingestion dose conversion factor (rem per picocurie)[h]	3.6×10^{-6}
Americium finfish bioaccumulation factor	250
Americium shellfish bioaccumulation factor	1,000
Americium meat transfer factor (days per kilogram)	3.5×10^{-6}
Americium milk transfer factor (days per liter)	4.0×10^{-7}
Neptunium ingestion dose conversion factor (rem per picocurie)	4.4×10^{-6}
Neptunium finfish bioaccumulation factor	250
Neptunium shellfish bioaccumulation factor	400
Neptunium meat transfer factor (days per kilogram)	5.5×10^{-5}
Neptunium milk transfer factor (days per liter)	5.0×10^{-6}
Technetium ingestion dose conversion factor (rem per picocurie)	1.5×10^{-9}
Technetium finfish bioaccumulation factor	15
Technetium shellfish bioaccumulation factor	5
Technetium meat transfer factor (days per kilogram)	8.5×10^{-3}
Technetium milk transfer factor (days per liter)	1.2×10^{-2}
Plutonium ingestion dose conversion factor (rem per picocurie)[i]	3.5×10^{-6}
Plutonium finfish bioaccumulation factor	250
Plutonium shellfish bioaccumulation factor	100
Plutonium meat transfer factor (days per kilogram)	5.0×10^{-7}
Plutonium milk transfer factor (days per liter)	1×10^{-7}
Yield of leafy vegetables [kilograms (wet) per square meter]	2.0
Yield of vegetables [kilograms (wet) per square meter]	2.0
Yield of meat feed crops [kilograms (wet) per square meter]	0.7
Yield of milk animal feed crops [kilograms (wet) per square meter]	0.7
Meat animal intake rate for feed (liters per day)	68
Milk animal intake rate for feed (liters per day)	55
Meat animal intake rate for water (liters per day)	50
Milk animal intake rate for water (liters per day)	60
Agricultural areal soil density (kilograms per square meter)	240
Retention fraction of activity on plants	0.25
Translocation factor for leafy vegetables	1.0
Translocation factor for other vegetables	0.1
Translocation factor for meat animal	0.1
Translocation factor for milk animal	1.0
Fraction of meat feed contaminated	1.0
Fraction of milk feed contaminated	1.0
Fraction of meat water contaminated	1.0
Fraction of milk water contaminated	1.0
Meat animal soil intake rate (kilograms per day)	0.5

Table K-9. Multimedia Environmental Pollutant Assessment System human exposure input parameters for determination of all pathways radiological impacts sensitivity analysis (page 2 of 2).[a]

Water source[b]	Surface water
Milk animal soil intake rate (kilograms per day)	0.5
Leafy vegetable growing period (days)	60
Other vegetable growing period (days)	60
Beef animal feed growing period (days)	30
Milk animal feed growing period (days)	30
Water intake rate while showering (liters per hour)	0.06
Duration of shower exposure (hours per shower)	0.167
Shower frequency (per day)	1.0
Thickness of shoreline sediment (meters)	0.04
Density of shoreline sediments (grams per cubic meter)	1.5
Shore width factor for shoreline external exposure	0.2

a. Source: DIRS 101936-Toblin (1999, pp. 4 and 5).
b. Groundwater for gardener.
c. No for gardener.
d. Zero for gardener.
e. To convert liters to gallons, multiply by 0.26418.
f. To convert liters per square meter to gallons per square foot, multiply by 0.00025.
g. To covert kilograms to pounds, multiply by 2.2046.
h. Sediment ingestion = 0.1 grams per hour (0.000022 pound per hour) during contact.
i. For plutonium-239/240.

Table K-10. Multimedia Environmental Pollutant Assessment System groundwater transport input parameters for estimating radiological impacts to the onsite and near-site gardener.[a]

Parameter	Region 1	Region 2	Region 3	Region 4	Region 5
Vadose zone					
Contaminated liquid infiltration rate (vertical Darcy velocity) (feet per year)[b,c]	3.5	4.4	2.7	3.5	0.88
Clay content (percent)	1	10	12	11	2
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5-9
Thickness (feet)	11	44	7.1	43	180
Longitudinal dispersivity (feet)	0.11	0.44	0.071	0.43	1.8
Bulk density (grams per cubic meter)[d]	1.6	1.5	1.5	1.5	1.6
Total porosity (percent)	38	42	44	45	41
Field capacity (percent)	9.3	15	23	21	12
Saturated hydraulic conductivity (feet per year)	6,500	660	1,700	1,000	5,900
Aquifer					
Clay content (percent)	1.8	6.5	1.2	4.4	0.69
pH of pore water	5 - 9	5 - 9	5 - 9	5 - 9	5 - 9
Thickness (feet)	45	50	37	64	210
Bulk density (grams per cubic meter)	1.6	1.8	1.6	1.6	1.7
Total porosity (percent)	38	40	38	35	30
Effective porosity (percent)	22	23	22	20	17
Darcy velocity (feet per year)	340	62	69	51	300
Longitudinal dispersivity (feet)	f(x)[e]	f(x)	f(x)	f(x)	f(x)
Lateral dispersivity (feet)	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3	f(x) ÷ 3
Vertical dispersivity (feet)	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400	f(x) ÷ 400
Maximum annual plutonium-239 and -240 release (curies per year)	4.9	0.24	3.8	0.32	2.1
Years (from 2016) of maximum annual plutonium release	1,365	1,575	1,155	1,715	875

a. Source: DIRS 101937-Toblin (1998, p. 2-4).
b. Annual precipitation rate (through degraded structure).
c. To convert feet to meters, multiply by 0.3048.
d. To convert grams per cubic meter to pounds per cubic foot, multiply by 0.0000624.
e. $f(x) = 2.72 \times (\log_{10} 0.3048 \times x)^{2.414}$, where x = downgradient distance.

parameters in Table K-9 describe the radionuclide exposure to the gardener where applicable (for example, exposure parameters related to the fish are not applicable to the gardener).

K.2.4.2 Direct Exposure

The analysis evaluated potential external radiation dose rates to the maximally exposed individual for a commercial independent spent fuel storage installation because this type of facility would provide the highest external exposures of all the facilities analyzed in this appendix. Maximum dose rates over the 10,000-year analysis period were evaluated for each region. The maximally exposed individual was assumed to be 10 meters (about 33 feet) from an array of concrete storage modules containing 1,000 MTHM of commercial spent nuclear fuel. The maximum dose rate varied between regions depending on how long the concrete shielding would remain intact (Table K-1).

The direct gamma radiation levels were calculated (DIRS 101556-Davis 1998, all). To ensure consistency between this analysis and the TSPA-VA, the same radionuclides were used for the design of the Yucca Mountain Repository surface facility shielding (DIRS 104603-CRWMS M&O 1995, Attachment 9.5). Radionuclide decay and radioactive decay product ingrowth over the 10,000-year analysis period were calculated using the ORIGEN computer program (DIRS 147923-RSIC 1991, all).

Neutron emissions were not included because worst-case impacts (death within a short period of exposure) would be the same with or without the neutron component.

K.2.5 ACCIDENT METHODOLOGY

Spent nuclear fuel and high-level radioactive waste stored in above-ground dry storage facilities would be protected initially by the robust surrounding structure (either metal or concrete) and by a steel storage container that contained the material. Normal storage facility operations would be primarily passive because the facilities would be designed for cooling via natural convection. DOE evaluated potential accident and criticality impacts for both Scenario 1 (institutional control for 10,000 years) and Scenario 2 (assumption of no effective institutional control after approximately 100 years with deterioration of the engineered barriers initially protecting the spent nuclear fuel or high-level radioactive waste).

For Scenario 1, human activities at each facility would include surveillance, inspection, maintenance, and equipment replacement when required. The facilities and the associated systems, which would be licensed by the Nuclear Regulatory Commission, would have certain required features. License requirements would include isolation of the stored material from the environment and its protection from severe accident conditions (10 CFR 50.34). The Nuclear Regulatory Commission requires an extensive safety analysis that considers the impacts of plausible accident-initiating events such as earthquakes, fires, high winds, and tornadoes. No plausible accident scenarios have been identified that result in the release of radioactive material from the storage facilities (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). In addition, the license would specify that facility design requirements include features to provide protection from the impacts of severe natural events. These requirements and analyses must demonstrate that the facilities can withstand the most severe wind loading (tornado winds and tornado-generated missiles) and flooding from the Probable Maximum Hurricane with minimal release of radioactive material. This analysis assumed maintenance of these features indefinitely for the storage facilities.

DOE performed a scoping analysis to identify the kinds of events that could lead to releases of radioactive material to the environment prior to degradation of concrete storage modules and found none. The two events determined to be the most challenging to the integrity of the concrete storage modules would be the crash of an aircraft into the storage facility and a severe seismic event.

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Spent nuclear fuel and high-level radioactive waste stored in above-ground dry storage facilities would be protected initially by the robust surrounding structure (either metal or concrete) and by a steel storage container that contained the material. Normal storage facility operations would be primarily passive because the facilities would be designed for cooling via natural convection. DOE evaluated potential accident and criticality impacts for both Scenario 1 (institutional control for 10,000 years) and Scenario 2 (assumption of no effective institutional control after approximately 100 years with deterioration of the engineered barriers initially protecting the spent nuclear fuel or high-level radioactive waste).

For Scenario 1, human activities at each facility would include surveillance, inspection, maintenance, and equipment replacement when required. The facilities and the associated systems, which would be licensed by the Nuclear Regulatory Commission, would have certain required features. License requirements would include isolation of the stored material from the environment and its protection from severe accident conditions (10 CFR 50.34). The Nuclear Regulatory Commission requires an extensive safety analysis that considers the impacts of plausible accident-initiating events such as earthquakes, fires, high winds, and tornadoes. No plausible accident scenarios have been identified that result in the release of radioactive material from the storage facilities (DIRS 103449-PGE 1996, all; DIRS 103177-CP&L 1989, all). In addition, the license would specify that facility design requirements include features to provide protection from the impacts of severe natural events. These requirements and analyses must demonstrate that the facilities can withstand the most severe wind loading (tornado winds and tornado-generated missiles) and flooding from the Probable Maximum Hurricane with minimal release of radioactive material. This analysis assumed maintenance of these features indefinitely for the storage facilities.

DOE performed a scoping analysis to identify the kinds of events that could lead to releases of radioactive material to the environment prior to degradation of concrete storage modules and found none. The two events determined to be the most challenging to the integrity of the concrete storage modules would be the crash of an aircraft into the storage facility and a severe seismic event.

- DIRS 103711-Davis, Strenge, and Mishima (1998, all) evaluated the postulated aircraft crash and subsequent fire at a storage facility. The analysis showed that falling aircraft components produced by such an event would not penetrate the storage facility and that a subsequent fire would not result in a release of radioactive materials.

- For the seismic event, meaningful damage would be unlikely because storage facilities would be designed to withstand severe earthquakes. Even if such an event caused damage, no immediate release would occur because no mechanism has been identified that would cause meaningful fuel pellet damage to create respirable airborne particles. If this damage did not occur, the source term would be limited to gaseous fission products, carbon-14, and a very small amount of preexisting fuel pellet dust. Subsequent repairs to damaged facilities or concrete storage modules would preclude the long-term release of radionuclides.

Criticality events are not plausible for Scenario 1 because water, which is required for criticality, could not enter the dry storage canister. The water would have to penetrate several independent barriers, all of which would be maintained and replaced as necessary under Scenario 1.

Under Scenario 2, facilities would degrade over time and the structures would gradually deteriorate and lose their integrity. The analysis determined that two events, an aircraft crash and inadvertent criticality, would be likely to dominate the impacts from accidents, as described in the following paragraphs.

K.2.5.1 Aircraft Crash

DOE determined that an aircraft crash into a degraded concrete storage module would be a severe accident-initiating event that could occur at the storage sites. This event would provide the potential for the airborne dispersion of radioactive material to the environment and, as a result, the potential for exposure of individuals who lived in the vicinity of the site. The aircraft crash could result in mechanical damage to the storage casks and the fuel assemblies they contained, and a fire could result. The fire would provide an additional mechanism for dispersion of the radioactive material. The frequency and consequences of this event are described in detail in DIRS 103711-Davis, Strenge, and Mishima (1998, all).

The aircraft assumed for the analysis is a midsize twin-engine commercial jet (DIRS 103711-Davis, Strenge, and Mishima 1998, p. 2). The area affected by a crash was computed using the DOE standard formula (DIRS 101810-DOE 1996, Chapter 6) in which the aircraft could crash directly into the side or top of the concrete storage modules, or could strike the ground in the immediate vicinity of the facility and skid into the concrete storage modules. Using this formula, the dimensions of a typical storage facility as shown in Chapter 2, Figure 2-33, and the aircraft configuration would result in an estimated aircraft crash frequency of 0.0000032 (3 in 1 million) crashes per year (DIRS 103711-Davis, Strenge, and Mishima 1998, p. 5). This frequency is within the range that DOE typically considers the design basis, which is defined by DOE as 0.000001 or greater per year (DIRS 104601-DOE 1993, p. 28).

The analysis estimated the consequences of the aircraft crash on degraded concrete storage modules. The twin-engine jet was assumed to crash into an independent spent fuel storage installation that contained 100 concrete storage modules, each containing 24 pressurized-water reactor fuel assemblies. Using the penetration methodology from DIRS 101810-DOE (1996, Chapter 6), an aircraft crash onto these concrete storage modules could penetrate 0.8 meter (2.6 feet). Because the concrete storage modules have thicker walls, the crash projectiles would not penetrate the reinforced concrete in the as-constructed form. Thus, DOE determined that the aircraft crash would not cause meaningful consequences until the concrete storage modules were considerably degraded, when an aircraft projectile could penetrate a concrete storage module and damage a storage cask (DIRS 103711-Davis, Strenge, and Mishima 1998, p. 7). The degradation process is highly location-dependent, as noted in Section K.2.1.1. For sites in northern climates, the degradation would be relatively rapid due to the freeze/thaw cycling that would expedite concrete breakup; considerable degradation could occur in 200 to 300 years. For southern climates, the degradation would be much slower. Thus, an aircraft crash probably would not result in meaningful consequences for a few hundred to a few thousand years, depending on location. The timing is of some importance because the radioactive materials in the fuel would decay over time, and the potential for radiation exposure would decline with the decay.

The analysis assumed that the aircraft crash occurred 1,000 years after the termination of institutional control at a facility where the concrete had degraded sufficiently to allow breach of the dry storage canister. Computing public impacts from the air crash event requires estimating the population to a distance of 80 kilometers (50 miles) from a hypothetical site (the distance beyond which impacts from an airborne release would be very small). This analysis considered two such sites, one in an area of a high population site and one in an area of low population. The average population around all of the sites in each of the five regions defined in Figure K-2 was computed based on 1990 census data. The average ranged from a high of 330 persons per square mile in region 1 (high population) to a low of 77 persons per square mile in region 4 (low population). Both of these population densities (assumed to be uniform around the hypothetical sites) were used in the consequence calculation.

Estimating the amount of airborne respirable particles that would result from a crash requires assumptions about the impact and resulting fire. The impact of the jet engines probably would cause extensive damage to the fuel assemblies in the degraded concrete storage module. The fuel tanks in the aircraft would rupture, and fuel would disperse around the site, collect in pools, and ignite into a fire. The estimated fraction of the fuel converted to respirable airborne dust would be 0.12 percent (DIRS 103711-Davis, Strenge, and Mishima 1998, p. 9). The fire would cause a thermal updraft that could loft the fuel pellet dust into the atmosphere.

The consequences from the event were computed with the MACCS2 program (DIRS 101897-Jow et al. 1990, all). This model has been used extensively by the Nuclear Regulatory Commission and DOE to estimate impacts from accident scenarios involving releases of radioactive materials. The model computes dose to the public from the direct radiation by the cloud of radioactive particles released during the accident, from inhaling particles, and from consuming food produced from crops and grazing land that could be contaminated as the particles are deposited on the ground from the passing cloud. The food production and consumption rates are based on generic U.S. values (DIRS 103776-Kennedy and Strenge 1992, pp 6.19 to 6.28; DIRS 103168-Chanin and Young 1998, all). The program computes the dispersion of the particles as the cloud moves downwind. The dispersion would depend on the weather conditions (primarily wind speed, stability, and direction) that existed at the time of the accident. This calculation assumed median weather conditions and used annual weather data from airports near the centers of the regions.

K.2.5.2 Criticality

DOE evaluated the potential for nuclear criticality accidents involving stored spent nuclear fuel. A criticality accident is not possible in high-level radioactive waste because most of the fissionable atoms were removed or the density of fissionable atoms was reduced by the addition of glass matrix. Nuclear criticality is the generation of energy by the fissioning (splitting) of atoms as a result of collisions with neutrons. The energy release rate from the criticality event can be very low or very high, depending on several factors, including the concentration of fissionable atoms, the availability of moderating materials to slow the neutrons to a speed that enables them to collide with the fissionable atoms, and the presence of materials that can absorb neutrons, thus reducing the number of fission events.

Criticality events are of concern because under some conditions they could result in an abrupt release of radioactive material to the environment. If the event were energetic enough, the dry storage canister could split open, fuel cladding failure could occur, and fragmentation of the uranium dioxide fuel pellets could occur.

The designs of existing dry storage systems for spent nuclear fuel, in accordance with Nuclear Regulatory Commission regulations (10 CFR Part 72) preclude criticality events by various measures, including primarily the prevention of water entering the dry storage canister. If water is excluded, a criticality cannot occur.

If institutional control was maintained at the dry storage facilities (Scenario 1), a criticality is not plausible because the casks would be monitored and maintained such that introduction of water into the canister would not be possible. However, under Scenario 2, eventual degradation (corrosion) of the dry storage canisters could lead to the entry of water from precipitation, at which point criticality could be possible if other conditions were met simultaneously.

The analysis considered three separate criticality events:

- A low-energy event that involved a criticality lasting over an intermediate period (minutes or more). This event would not produce high temperatures or generate large additional quantities of radionuclides. Thus, no fuel cladding failures and no meaningful increase in consequences would be likely.

- An event in which a system went critical but at a slow enough rate so the energy release would not be large enough to produce steam, which would terminate the event. This event could continue over a relatively long period (minutes to hours), and would differ from the low-energy event in that the total number of fissions could be very large, and a large increase in radionuclide inventory could result. This increase could double the fission product content of the spent nuclear fuel. No fuel cladding failures would be likely in this event, so no abrupt release of radionuclides would occur.

- An energetic event in which a system went critical and produced considerable fission energy. This event could occur if seriously degraded fuel elements collapsed abruptly to the bottom of the canister in the presence of water that had penetrated the canister. This event would produce high fuel temperatures that could lead to cladding rupture and fuel pellet oxidation. The radiotoxicity of the radionuclide inventory produced by the fission process would be comparable to the inventory in the fuel before the event.

The probability of a criticality occurring as described in these scenarios is highly uncertain. However, DOE expects the probability would be higher for the first two events, and much lower for the third (energetic energy release). Several conditions would have to be met for any of the three events to occur. The concrete storage module and dry storage canister must have degraded such that water could enter but not drain out. The fuel would have to contain sufficient fissionable atoms (uranium-235, plutonium 239) to allow criticality. This would depend on initial enrichment (initial concentration of uranium-235) and burnup of the fuel in the reactor before storage (which would reduce the uranium-235 concentration). Because a small amount of spent nuclear fuel would be likely to have appropriate enrichment burnup combinations that could enable criticality to occur, none of the criticality events can be completely ruled out. The energetic criticality event is the only one with the potential to produce large impacts. Such an event would be possible, but would be highly unlikely; its consequences would be uncertain. The event could cause a prompt release of radionuclides. However, the amount released would not be likely to exceed that released by the aircraft crash event evaluated above. Thus, this analysis did not evaluate specific consequences of a criticality event.

K.3 Results

K.3.1 RADIOLOGICAL IMPACTS

Impacts to human health from long-term environmental releases and human intrusion were estimated using the methods described in Section K.2 and in supporting technical documents (DIRS 101925-Sinkowski 1998, all; DIRS 101852-Jenkins 1998, all; DIRS 104597-Battelle 1998, all; DIRS 101910, 101911-Poe 1998, all; DIRS 101912-Poe and Wise 1998, all; DIRS 101935-Toblin 1999, all; DIRS 101936-Toblin 1999, all; DIRS 101937-Toblin 1998, all). The radiological impacts on human health would include internal exposures due to the intake of radioactive materials released to surface water and groundwater.

Six of the seven radionuclides listed in Table K-4 would contribute more than 99 percent of the total dose. Table K-11 lists the estimated radiological impacts by region during the last 9,900 years under Scenario 2 for the Proposed Action and Module 1 inventories of spent nuclear fuel and high-level radioactive waste. As noted above, these impacts would be to the public from drinking water from the major waterways contaminated by surface-water runoff of radioactive materials from degraded spent nuclear fuel and high-level radioactive waste storage facilities (DIRS 101935-Toblin 1999, all; DIRS 101936-Toblin 1999, all). Figure K-7 shows the locations of all commercial nuclear and DOE waste storage sites in the United States and more than 20 potentially affected major waterways. At present, 30.5 million people are served by municipal water systems with intakes along the potentially affected portions of these waterways. Over the 9,900-year analysis period, about 140 generations would be potentially affected. However, because releases are not estimated to occur during about the first 1,000 years for most regions, the potential affected population could be as high as 3.9 billion.

SCENARIO 2 IMPACTS

The principal long-term human health consequences from the storage of spent nuclear fuel and high-level radioactive waste would result from rainwater flowing through degraded storage facilities where it would dissolve the material. The dissolved material would travel through groundwater and surface-water runoff to rivers and streams where people could use it for domestic purposes such as drinking water and crop irrigation. The Scenario 2 analysis estimated population impacts resulting only from the consumption of contaminated drinking water and exposures resulting from land contamination due to periodic flooding, although other pathways, such as eating contaminated fish, could contribute additional impacts larger than those from drinking water for selected individuals in the exposed population.

Table K-11 indicates the variability of collective doses and potential impacts in the five regions analyzed (see Section K.2.1.6). The variability among regions is due to differences in types and quantities of spent nuclear fuel and high-level radioactive waste, annual precipitation, size of affected populations, and surface-water bodies available to transport the radioactive material.

Table K-11 also indicates that the Proposed Action inventory would produce a collective drinking water dose of 6.6 million person-rem over 9,900 years, which could result in an additional 3,300 latent cancer fatalities in the total potentially exposed population of 3.9 billion, in which about 900 million fatal cancers [using the lifetime fatal cancer risk of 24 percent (DIRS 101849-NCHS 1993, p. 5)] would be likely to occur from all other causes. Figures K-8 and K-9 show the Proposed Action inventory regional collective doses and potential latent cancer fatalities, respectively, for approximately 140 consecutive 70-year lifetimes that would occur during the 9,900-year analysis period. The peaks shown in Figures K-8 and K-9 would result from the combination of the sites that drain to the Mississippi River and the relatively large populations potentially affected along these waterways. These values include

Table K-11. Estimated collective radiological impacts to the public from continued storage of Proposed Action and Module 1 inventories of spent nuclear fuel and high-level radioactive waste at commercial and DOE storage facilities – Scenario 2.[a]

	9,900-year population dose[b] (person-rem)		9,900-year LCFs		Years until peak impact[c]	
Region	Proposed Action	Module 1	Proposed Action	Module 1	Proposed Action	Module 1
1	1,800,000	1,820,000	900	900	1,400	1,400
2	760,000	1,260,000	380	630	5,100	8,300
3	3,500,000	3,650,000	1,800	1,830	3,400[d]	3,400[d]
4	70,000	138,000	30	69	3,900	3,900
5	460,000	461,000	230	230	7,100	7,000
Totals	***6,590,000***	***7,330,000***	***3,340***	***3,700***		

a. Total population (collective) dose from drinking water pathway over 9,900 years.
b. LCF = latent cancer fatality; additional number of latent cancer fatalities for the exposed population group based on an assumed risk of 0.0005 latent cancer fatality per person-rem of collective dose (DIRS 101857-NCRP 1993, p. 112).
c. Years after 2116 when the maximum doses would occur.
d. Year of combined U.S. peak impact would be the same as for Region 3 peak impact, because the predominant impact would be in Region 3.

impacts for the Proposed Action inventory only. Similar curves for the Module 1 inventory are not shown because of their similarity to those for the Proposed Action inventory. As listed in Table K-11, the impacts from the Module 1 inventory would be approximately 20 percent greater than for the Proposed Action inventory.

The additional 3,300 Proposed Action latent cancer fatalities (or 3,700 Module 1 latent cancer fatalities) over the 10,000-year analysis period would not be the only negative impact. Under Scenario 2, more than 20 major waterways of the United States (for example, the Great Lakes, the Mississippi, Ohio, and Columbia rivers, and many smaller rivers along the Eastern Seaboard) that currently supply domestic water to 30.5 million people would be contaminated with radioactive material. The shorelines of these waterways would be contaminated with long-lived radioactive materials (plutonium, uranium, americium, etc.) that would result in exposures to individuals who came into contact with the sediments, potentially increasing the number of latent cancer fatalities. Each of the 72 commercial and 5 DOE sites throughout the United States would have potentially hundreds of acres of land and underlying groundwater systems contaminated with radioactive materials at concentrations that would be potentially lethal to anyone who settled near the degraded storage facilities. The radioactive materials at the degraded facilities and in the floodplains and sediments would persist for hundreds of thousands of years.

As mentioned above, DOE only estimated potential collective impacts resulting from the consumption of contaminated surface water. However, other pathways (food consumption, contaminated floodplains, etc.) that could contribute to collective dose were evaluated (DIRS 101936-Toblin 1999, all; DIRS 150990-Rollins 1998, all) to determine their relative importance to the drinking water pathway. These pathways included the following:

- Consumption of vegetables irrigated with contaminated water
- Consumption of meat and milk from animals that drank contaminated water or were fed with contaminated feed
- Consumption of contaminated finfish and shellfish
- Direct exposure to contaminated shoreline sediments
- Exposures resulting from contamination of floodplains during periods of high stream (river) flow

These analyses determined that an individual living in a contaminated floodplain and consuming vegetables irrigated with contaminated surface water could receive a radiation exposure dose three times

Figure K-7. Major waterways near commercial and DOE sites.

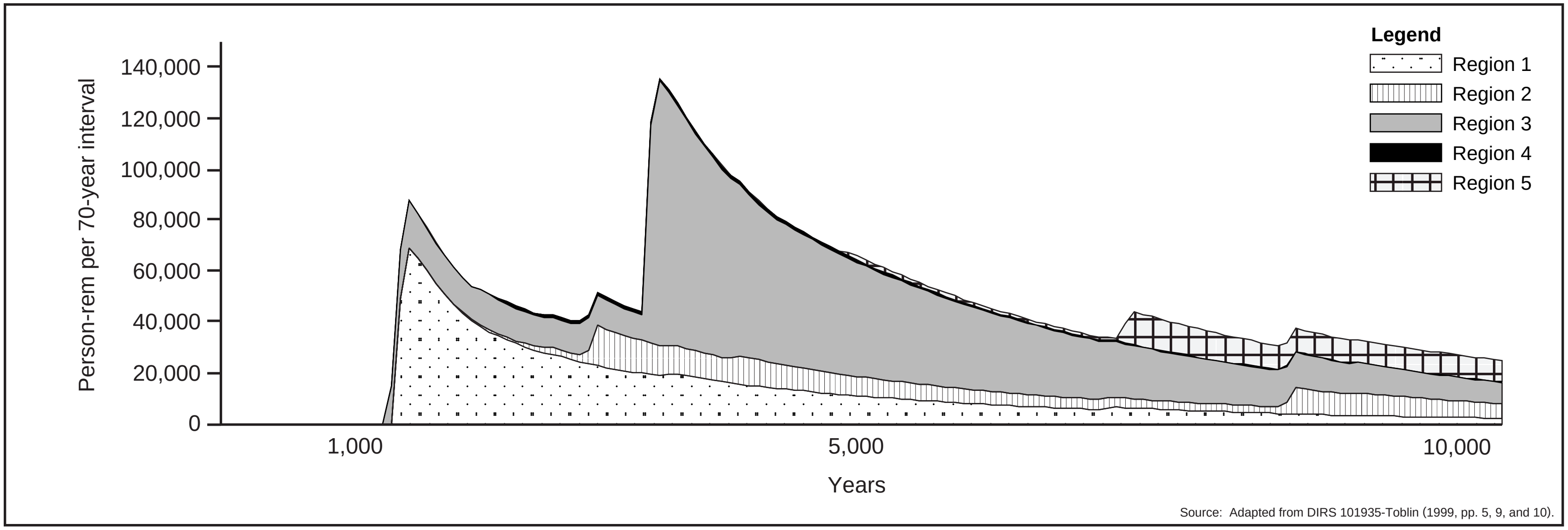

Figure K-8. Regional collective dose from the Proposed Action inventory under No-Action Scenario 2.

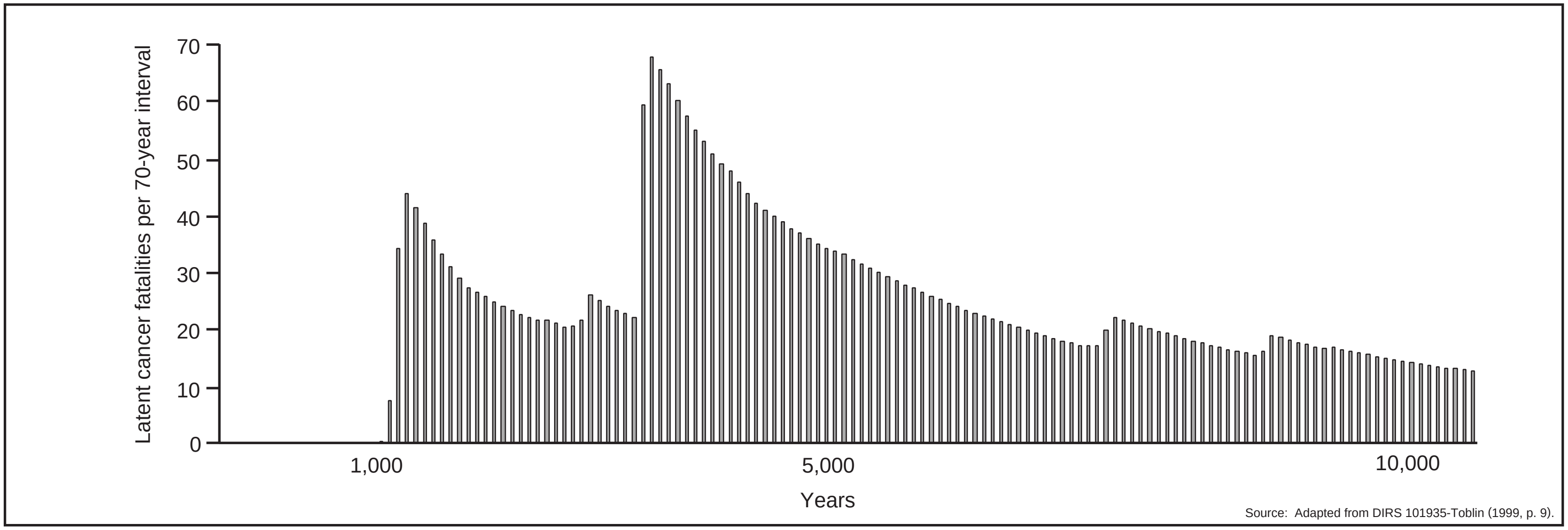

Figure K-9. Total potential latent cancer fatalities throughout the United States from the Proposed Action inventory under No-Action Scenario 2.

higher than that from the consumption of contaminated surface water only (DIRS 101936-Toblin 1999, p. 3). In addition, the analysis determined that impacts to 30 million individuals potentially living in contaminated floodplains would be less than 10 percent of the collective impacts shown in Figure K-9 and, therefore, did not include them in the estimates because DOE did not want to overestimate the impacts from Scenario 2.

DOE evaluated airborne pathways (DIRS 147905-Mishima 1998, all) and judged that potential impacts from those pathways would be very small in comparison to impacts from liquid pathways because the degraded facility structures would protect the radioactive material from winds. To simplify the analysis, impacts to the public from radiation emanating from the degraded storage facilities were not included. Those impacts were judged to represent a small fraction of the impacts calculated for the liquid pathways (Table K-11).

Estimates of localized impacts (DIRS 101937-Toblin 1998, p. 1) assumed that individuals (onsite and near-site gardeners) would take up residence near the degraded storage facilities and would consume vegetables from their gardens irrigated with groundwater withdrawn from the contaminated aquifer directly below their locations. In addition, the onsite gardener would be exposed to external radiation emanating from the exposed dry storage canisters; therefore, the onsite gardener would be the maximally exposed individual.

Table K-12 lists the internal estimated dose rates (see Section K.2.4.1 for details) and the times for peak exposure for each of the five regions.

Table K-12. Estimated internal dose rates (rem per year) and year of peak exposure[a] (in parentheses) for the onsite and near-site gardeners – Scenario 2.[b]

	Maximally exposed individual distances (meters)[c] from storage facilities			
Region	10[d]	150	1,000	5,000
1	3,100 (1,800)	670 (2,200)	51 (2,000)	12 (2,600)
2	100 (2,700)	96 (2,000)	12 (2,900)	2 (7,100)
3	3,100 (1,800)	1,800 (2,000)	150 (2,600)	31 (6,000)
4	140 (3,200)	130 (3,900)	14 (4,800)	2 (9,300)
5	3,300 (4,600)	180 (5,300)	59 (5,300)	2 (6,100)

a. Years after facility maintenance ended.
b. Source: Adapted from DIRS 101937-Toblin (1998, Table 4, p. 5).
c. To convert meters to feet, multiply by 3.2808.
d. The maximally exposed individual would be the onsite gardener.

The regional dose rates listed in Table K-12 would depend on the concentration of contaminants (primarily plutonium) in the underlying aquifer from which water was extracted and used by the gardener for consumption and crop irrigation. These aquifer concentrations, in turn, would be affected by the type and location of stored materials (spent nuclear fuel and high-level radioactive waste) in each region, the rate at which the contaminants were leached from the stored material, the amount of water (precipitation) available for dilution, and the thickness of the aquifer. For example, releases in Region 5 would probably be smaller and would occur later than those in other regions because of the region's lack of precipitation. This is indeed the case for commercial fuel, which is stored in above-grade concrete storage modules, stainless-steel dry storage canisters, and mostly intact corrosion-resistant zirconium alloy cladding.

However, early releases would occur in Region 5 because most DOE spent nuclear fuel is stored in below-grade vaults (see Appendix A, p. A-25) that would stop providing rain protection after 50 years (see Section K.2.1.1 for details). In addition, the analysis assumed no credit for the protectiveness of the DOE spent nuclear fuel cladding (see Section K.2.1.4.2 for details), which would result in releases that began early (about 800 years after weather protection was lost) and persist at a nearly constant rate for more that 6,000 years (DIRS 101937-Toblin 1998, p. 3).

The 10-meter (33-foot) doses listed in Table K-12 would be due to leachate concentrations from the storage area with no groundwater dilution. Downgradient doses decrease more rapidly in Regions 1 and 5 than in other regions because of greater groundwater dilution. The downgradient decrease in Region 5 would also be due to the relatively thick aquifer, which results in greater vertical plume spread and increases plume attenuation (DIRS 101937-Toblin 1998, pp. 4 to 6).

As shown in Table K-12, an onsite gardener in Region 5 could receive an internal committed dose as high as 3,300 rem for each year of ingestion of plutonium-239 and -240. However, the individual actually would receive only about 70 rem the first year, 140 rem the second year, 210 rem the third year, and so on until reaching an equilibrium annual dose (in approximately 50 years) of 3,300 rem per year. The individual would continue to receive this equilibrium dose as long as the radioactive material uptake remained constant.

If the annual doses are added, in less than 10 years the individual would have received more than 2,000 rem. If the International Commission on Radiological Protection risk conversion factor were applied to this dose, a probability of fatal cancer induction of 1 could be calculated. In other words, the use of this risk conversion would predict that 10 years of exposure would be virtually certain to produce a fatal cancer. This calculated risk is approximately 4 times greater than the lifetime risk of contracting a fatal cancer from all other causes (24 percent).

Table K-13 shows that the direct radiation dose rate to the onsite gardener could be as high as 7,300 rem per year. Unlike internal dose, this dose would actually be delivered during the year of exposure. This maximum value assumes a complete loss of shielding normally provided by the concrete storage module at the same time as the loss of weather protection (see Table K-1). Assuming a dose of 7,300 rem per year, the individual probably would die from acute radiation exposure. This dose would probably cause extensive cell damage in the individual that would result in severe acute adverse health conditions and death within weeks or months (DIRS 106184-NRC 1996, p. 8.29-5). However, these higher radiation dose rates are based on an early estimated time to structural failure of the concrete storage module. If these failure times were extended by as little as 100 years, the associated dose rates would decrease by a factor of 10 because the levels of radiation emanating from the degraded facilities would have decreased by about a factor of 10 due to radioactive decay (DIRS 150990-Rollins 1998, p. 12).

Table K-13. Estimated external peak dose rates (rem per year) for the onsite and near-site gardeners – Scenario 2.

		Maximally exposed individual distances (meters)[a] from storage facilities			
Region	Year of peak exposure[b]	10[c]	150	1,000	5,000
1	190	7,200	4	0.001	0.0
2	800	28	0.04	0.0	0.0
3	170	7,300	4	0.001	0.0
4	850	31	0.04	0.0	0.0
5	3,600	32	0.05	0.0	0.0

a. To convert meters to feet, multiply by 3.2808.
b. Years after 2116; Source: Adapted from DIRS 101910-Poe (1998, all).
c. Source: Adapted from (DIRS 101556-Davis 1998, all); the maximally exposed individual would be the onsite gardener.

The internal and external dose rates are presented separately because they would occur at different times and are therefore not additive.

K.3.2 UNUSUAL EVENTS

This section includes a quantitative assessment of potential accident impacts and a qualitative discussion of the impacts of sabotage.

K.3.2.1 Accident Scenarios

The analysis examined the impacts of accident scenarios that could occur during the above-ground storage of spent nuclear fuel and high-level radioactive waste and concluded that the most severe accident scenarios would be an aircraft crash into concrete storage modules or a severe seismic event. In Scenario 1, where storage would be in strong rigid concrete storage modules that had not degraded, the accident would not be expected to release radioactive material.

In Scenario 2, the concrete storage modules would deteriorate with time. If a severe natural event (for example, a hurricane) were to strike a degraded facility, a release of radioactive materials could occur earlier than predicted (see Section K.2) because of damage to the engineered barriers (concrete storage modules, dry storage canisters, material cladding, etc.). Section K.4 describes the potential effect of early loss of these barriers (see Table K-15 in Section K.4.3.1). However, DOE concluded that an aircraft crash into degraded concrete storage modules would dominate the consequences. The analysis evaluated the potential for criticality accidents and concluded that an event severe enough to produce meaningful consequences would be extremely unlikely, and that the consequences would be bounded by the aircraft crash consequences. Table K-14 lists the consequences of an aircraft crash on a degraded spent fuel concrete storage module.

Table K-14. Consequences of aircraft crash onto degraded spent nuclear fuel concrete storage module.[a]

Factor	High-population site[b]	Low-population site[c]
Frequency (per year)	3.2×10^{-6}	3.2×10^{-6}
Collective population dose (person-rem)	26,000	6,000
Latent cancer fatalities	13	3

a. Source: DIRS 103711-Davis, Strenge, and Mishima (1998, p. 11).
b. 330 persons per square mile.
c. 77 persons per square mile.

K.3.2.2 Sabotage

Storage of spent nuclear fuel and high-level radioactive waste over 10,000 years would entail a continued risk of intruder access at each of the 77 sites. Sabotage could result in a release of radionuclides to the environment around the facility. In addition, intruders could attempt to remove fissile material, which could result in releases of radioactive material to the environment. For Scenario 1, the analysis assumed that safeguards and security measures currently in place would remain in effect during the 10,000-year analysis period at the 77 sites. Therefore, the risk of sabotage would continue to be low. However, the difficulty of maintaining absolute control over 77 sites for 10,000 years would suggest that the cumulative risk of intruder attempts would increase.

For Scenario 2, the analysis assumed that safeguards and security measures would not be maintained at the 77 sites after approximately the first 100 years. For the remaining 9,900 years of the analysis period, the cumulative risk of intruder attempts would increase. Therefore, the risk of sabotage would increase substantially under this scenario.

K.4 Uncertainties

Section K.3 contains estimates of the radiological impacts of the No-Action Alternative, which assumes continued above-ground storage of spent nuclear fuel and high-level radioactive waste at sites across the United States. Associated with the impact estimates are uncertainties typical of predictions of the outcome of complex physical and biological phenomena and of the future state of society and societal institutions over long periods. DOE recognized this fact from the onset of the analysis; however, the predictions will be valuable in the decisionmaking process because they provide insight based on the best information and scientific judgments available.

This analysis considered five aspects of uncertainty:

- Uncertainties about the nature of changes in society and its institutions and values, in the physical environment, and of technology as technology progresses
- Uncertainties associated with future human activities and lifestyles
- Uncertainties associated with the mathematical representation of the physical processes and with the data in the computer models
- Uncertainties associated with the mathematical representation of the biological processes involving the uptake and metabolism of radionuclides and the data in the computer models
- Uncertainties associated with accident scenario analysis

The following sections discuss these uncertainties in the context of possible effects on the impact estimates reported in Chapter 7 and Section K.3.

K.4.1 SOCIETAL VALUES, NATURAL EVENTS, AND IMPROVEMENTS IN TECHNOLOGY

K.4.1.1 Societal Values

History is marked by periods of great social upheaval and anarchy followed by periods of relative political stability and peace. Throughout history, governments have ended abruptly, resulting in social instability, including some level of lawlessness and anarchy. The Scenario 1 assumption is that political stability would exist to the extent necessary to ensure adequate institutional control to monitor and maintain the spent nuclear fuel and high-level radioactive waste to protect the workers and the public for 10,000 years. The Scenario 2 assumption is that in the United States political stability would exist for 100 years into the future and that the spent nuclear fuel and high-level radioactive waste would be properly monitored and maintained and the public would be protected for this length of time. If a political upheaval were to occur in the United States, the government could have difficulty protecting and maintaining the storage facilities, and the degradation processes could begin earlier than postulated in Scenario 2. If institutional control were not maintained for at least 100 years, radioactive materials from the spent nuclear fuel and high-level radioactive waste could enter the environment earlier, which would result in higher estimated impacts due to the higher radiotoxicity of the materials. However, this scenario would probably increase overall impacts by no more than a factor of 2.

K.4.1.2 Changes in Natural Events

Because of the difficulty of predicting impacts of climate change (glaciation, precipitation, global warming), DOE decided to evaluate facility degradation and environmental transport mechanisms based on current climate conditions. For example, glaciation, which many scientists agree will occur again within 100,000 years, probably would cover the northeastern United States with a sheet of ice. The ice would crush all structures, including spent nuclear fuel and high-level radioactive waste storage facilities, and could either disperse the radioactive materials in the accessible environment or trap the materials in the ice sheet. In addition, large populations would migrate from the northeastern United States to warmer climates, thus changing the population distribution and densities throughout the United States (the coastline could move 100 miles out from its current position due to the reduced water in the oceans). Other scientists predict that global warming could lead to extensive flooding of low-lying coastal areas throughout the world. Such changes would have to be known with some degree of certainty to make accurate estimates of potential impacts associated with the release of spent nuclear fuel and high-level radioactive waste materials to the environment. To simplify the analysis, DOE has chosen not to attempt to quantify the impacts resulting from the almost certain climate changes that will occur during the analysis period.

K.4.1.3 Improvements in Technology

We are living in a time of unparalleled technical advancement. It is possible that cures for many common cancers will be found in the coming decades. In this regard, the National Council on Radiation Protection and Measurements (DIRS 101858-NCRP 1995, p. 51) states that:

> *One of the most important factors likely to affect the significance of radiation dose in the centuries and millennia to come is the effect of progress in medical technology. At some future time, it is possible that a greater proportion of somatic [cancer] diseases caused by radiation will be treated successfully. If, in fact, an increased proportion of the adverse health effects of radiation prove to be either preventable or curable by advances in medical science, the estimates of long-term detriments may need to be revised as the consequences (risks) of doses to future populations could be very different.*

Effective cures for cancer would affect the fundamental premise on which the No-Action Alternative impact analysis is based. However, this technology change was not included in the impact analyses.

Other advancements in technology could include advancements in water purification that could reduce the concentration of contaminants in drinking water supplies. Improved corrosion-resistant materials could reduce package degradation rates, which could reduce the release of contaminants and the resultant impacts. In addition, future technology could enable the detoxification of the spent nuclear fuel and high-level radioactive waste materials, thereby removing the risks associated with human exposure.

K.4.2 CHANGES IN HUMAN BEHAVIOR

General guidance for the prediction of the evolution of society has been provided by the National Research Council in *Technical Bases for Yucca Mountain Standards* (DIRS 100018-National Research Council 1995, pp. 28 and 70), in which the Committee on Technical Bases for Yucca Mountain Standards concluded that there is no scientific basis for predicting future human behavior. The study recommends policy decisions that specify the use of default (or reference) scenarios to incorporate future human behaviors into compliance assessment calculations. This No-Action Alternative analysis followed this approach, based on societal conditions as they exist today. In doing so, the analysis assumed that populations would remain at their present locations and that population densities would remain at the current levels. This assumption is appropriate when estimating impacts for comparison with other proposed actions; however, it does not reflect reality.

Although this analysis did not project the affected populations used in the No-Action Alternative to 2035, as DOE has done in other parts of the EIS, the potential effect on the outcome would be an increase in collective impacts of less than a factor of 1.5, which is the average expected increase in national population from 1990 to 2035 (DIRS 152471-Bureau of the Census 2000, all). In addition to changing in size, populations are constantly moving. If, for example, populations were to move closer to and increase in size in areas near the storage facilities, the radiation dose and resultant adverse impacts could increase substantially. However, DOE has no way to predict such changes accurately and, therefore, did not attempt to quantify the resultant effects on overall impacts.

Another lifestyle change that could affect the overall impacts would involve food consumption patterns. For example, people might curtail their use of public water supplies derived from rivers if they learned that the river water carried carcinogens. Widespread adoption of such practices could reduce the impacts associated with the drinking water pathway.

K.4.3 MATHEMATICAL REPRESENTATIONS OF PHYSICAL PROCESSES AND OF THE DATA INPUT

The DOE approach for the No-Action Alternative was to be as comparable as possible to the approach used for the predictions of impacts from the proposed Yucca Mountain Repository to enable direct comparisons of the impact estimates for the two cases. Therefore, the analysis either used the process models developed for the TSPA-VA directly or adapted them for the No-Action Alternative impact calculations. For processes that were different from those treated in the TSPA-VA, DOE developed analytical approaches.

In a general sense, the TSPA-VA calculations used a stochastic (random) approach to develop radiological impact estimates. Existing process models were used to generate a set of responses for a particular process. In the TSPA-VA process, the impact calculations sample each set of process responses and calculate a particular impact result. A large number of calculations were performed. From the set of variable results, an expected value can be identified, as can a distribution of results that is an indication of the uncertainties in the calculated expected values.

For the No-Action Alternative analysis, the calculations were based on only a single set of best estimate parameters. No statistical distribution of results was generated as a basis for the quantification of uncertainties. This section describes the uncertainties associated with the input data and modeling used to evaluate the rates of degradation of the materials considered in this document and to estimate the impacts of the resulting releases. It describes the key assumptions, shows where the assumptions are consistent with TSPA-VA assumptions, and qualitatively assesses the magnitude of the uncertainties caused by the assumptions.

Calculating the radiological impacts to human receptors required a mathematical representation of physical processes (for example, water movement) and data input (for example, material porosity). There are uncertainties in both the mathematical representations and in the values of data. The TSPA-VA accommodates these uncertainties by using a probabilistic approach to incorporate the uncertainties, whereas the No-Action analysis uses a deterministic approach in combination with an uncertainty analysis. When done correctly, both approaches yield the same information, although, as in the case of the TSPA-VA, the probabilistic approach provides quantitative information.

K.4.3.1 Waste Package and Material Degradation

The major approaches and assumptions used for the No-Action Scenario 2 analysis are listed in Table K-15. The table indicates where the continued storage calculations followed the basic methods developed for the TSPA-VA. It also indicates the processes for which models other than those used in the TSPA-VA were applied.

DOE analyzed surface storage of commercial spent nuclear fuel in horizontal stainless-steel canisters inside concrete storage modules. There are other probable forms of storage, including horizontal and

Table K-15. Review of approaches, assumptions, and related uncertainties[a] (page 1 of 2).

Approach or assumption	Consistent with repository analysis assumptions	Sensitivity of impacts to approach or assumption[b]
Period of analysis – 10,000 years	Yes	None
Commercial spent nuclear fuel, DOE spent nuclear fuel, and high-level radioactive waste quantities equivalent to NWPA specified 70,000 MTHM and Module 1	Yes	None
No credit for stainless-steel cladding on commercial spent nuclear fuel	Yes	If credit were taken for stainless-steel cladding, LCFs[a] could decrease by as much as a factor of 10.
0.1 percent of zirconium alloy cladding is initially failed	Yes	If initial zirconium-alloy-clad fuel cladding failure had been assumed to be as low as zero or as high as 100 percent impacts could have been slightly smaller (additional protection from winds) to a factor of 20 higher, respectively.
Concrete storage module weather protection	This is a primary protective barrier for the No-Action analysis and is not applicable to TSPA	If weather protection from the concrete storage module had not been assumed in the No-Action analysis, LCFs could be higher by less than a factor of 10.
Concrete base pad degradation	Not applicable	Used NRC recommended values (probably overestimated degradation and reduced consequences in the No-Action analysis); increase in LCFs by probably more than a factor of 2 but less than a factor of 10
Credit for stainless-steel canister on high-level radioactive waste	No; TSPA does not take credit for stainless-steel container	If the No-Action analysis had not taken credit for the stainless-steel canister, LCFs would change very little (slight increase) because of the intrinsic stability of the borosilicate glass.
DOE spent nuclear fuel evaluated by a representative surrogate that is based mostly on DOE N-Reactor spent nuclear fuel (other spent nuclear fuel types not evaluated)	Yes	If actual fuel types were evaluated, LCFs could either increase or decrease by less than a factor of 2.
No credit given for zirconium alloy cladding on N-Reactor spent nuclear fuel	Yes	If credit was given for the N-Reactor zirconium alloy cladding, the LCFs would decrease by less than a factor of 2.
Stainless steel deterioration	Model paralleled TSPA approach for Alloy-22	Model based on best information; if incorrect and corrosion proceeds more rapidly and stainless steel offers no protection, LCFs would increase by less than 25 percent.
Zirconium alloy cladding deterioration	Yes, very slow corrosion rate.	If the No-Action analysis had assumed larger or smaller deterioration rates, LCFs could have increased by several orders of magnitude or decreased by less than a factor of 2.
Zirconium alloy cladding credit	Yes	If the No-Action analysis had not taken credit for zirconium alloy cladding, LCFs could have increased by as much as 2 orders of magnitude.
Deterioration of spent nuclear fuel and high-level radioactive waste core materials	Yes	None

Table K-15. Review of approaches, assumptions, and related uncertainties[a] (page 2 of 2).

Approach or assumption	Consistent with repository analysis assumptions	Sensitivity of impacts to approach or assumption[b]
Use of recent regional climate conditions to determine deterioration (temperature, precipitation, etc.)	No; No-Action analysis used constant "effective" regional weather parameters weighted for material inventories and potentially affected downstream populations; TSPA used actual weather patterns measured at Yucca Mountain. The TSPA also assumed long-term climate changes would occur in the form of increased precipitation.	If actual site climate data and projected future potential climate changes had been considered in the No-Action analysis, LCFs could have increased or decreased by as much as a factor of 10. Climate change assumptions such as a glacier covering most of the northeastern seaboard of the United States would have made estimating impacts from continued storage virtually impossible.
Surface transport by precipitation	Not applicable; TSPA only considered groundwater transport because there is no surface-water transport pathway possible for the repository.	If the No-Action analysis had not considered the groundwater transport pathway, LCFs could have been as much as a factor of 10 higher.
Regional binning of sites – not specific site parameters	Not applicable; TSPA considered only a single site; the No-Action analysis evaluated potential impacts from 77 sites on a regional basis.	The No-Action analysis binned sites into categories and developed "effective" regional climate conditions such that calculated impacts would be comparable to those which could be calculated by a site-specific analysis.
Atmospheric dose consequences judged to be small when compared to liquid pathways.	Yes	Small impact on LCFs.
Drinking water doses	Yes; primary pathway evaluated	Use of drinking-water-only pathway underestimates total collective LCFs by less than a factor of 3.
Used the Multimedia Environmental Pollutant Assessment System[c] modeling approach for calculating population uptake/ingestion	No; TSPA uses GENII-S.[d] GENII-S uses local survey data; the Multimedia Environmental Pollutant Assessment System uses EPA/NRC exposure/uptake default and actual population data	No impact. The two programs yield comparable results as used in these analyses.
ICRP[e] approach to calculate dose commitment from ingested radionuclides	Yes	No impact.
Human health impacts calculated as LCFs with NCRP[f] conversion factors	NA; TSPA does not estimate LCFs.	Use of other than the linear no-threshold model could result in a change in estimated LCFs from 0.25 to 2 times the nominal value.[g]

a. Abbreviations: NWPA = Nuclear Waste Policy Act; MTHM = metric tons of heavy metal; LCF = latent cancer fatality; TSPA = Total System Performance Assessment; NRC = Nuclear Regulatory Commission; ICRP = International Commission on Radiological Protection; EPA = Environmental Protection Agency.
b. Sensitivity of impacts to approach/assumption is based on professional judgement and, if applicable, the effects of the approaches/assumptions on calculations.
c. DIRS 101533-Buck et al. (1995, all).
d. DIRS 100464-Leigh et al. (1993, all).
e. DIRS 110386-ICRP (1979, all).
f. DIRS 101857-NCRP (1993, p. 112).
g. DIRS 101884-NCRP (1997, p. 75).

vertical casks made of materials ranging from stainless steel to carbon steel. Degradation and releases from vertical carbon-steel casks were evaluated qualitatively. Such storage units would be likely to fail from corrosion earlier than concrete and stainless steel. The concrete and stainless-steel units were calculated to fail and begin releasing their contents at about 1,000 years after the assumed loss of institutional control. The less-resistant carbon-steel units could begin releasing their contents earlier and their use would result in a longer period of release and increased impacts. This difference is likely to be an increase of 10 to 30 percent in population dose commitment and resultant latent cancer fatalities.

K.4.3.2 Human Health Effects

The dose-to-risk conversion factors typically used to estimate adverse human health impacts resulting from radiation exposures contain considerable uncertainty. The risk conversion factor of 0.0005 latent cancer fatality per person-rem of collective dose for the general public typically used in DOE National Environmental Policy Act documents is based on recommendations of the International Commission on Radiological Protection (DIRS 101836-ICRP 1991, p. 22) and the National Council on Radiation Protection and Measurements (DIRS 101857-NCRP 1993, p. 112). The factor is based on health effects observed in the high dose and high dose rate region (20 to 50 rem per year). Health effects were extrapolated to the low-dose region (less than 10 rem per year) using the linear no-threshold model. This model is generally recommended by the International Commission on Radiological Protection and the National Council of Radiation Protection and Measurements, and most radiation protection professionals believe this model produces a conservative estimate (that is, an overestimate) of health effects in the low-dose region, which is the exposure region associated with continued storage of spent nuclear fuel and high-level radioactive waste. This report summarizes estimates of the impacts associated with very small chronic population doses to enable comparison of alternatives in this EIS.

According to the National Council on Radiation Protection and Measurements, the results of an analysis of the uncertainties in the risk coefficients "show a range (90 percent confidence intervals) of uncertainty values for the lifetime risk for both a population of all ages and an adult worker population from about a factor of 2.5 to 3 below and above the 50th percentile value" (DIRS 101884-NCRP 1997, p. 74).

The National Council on Radiation Protection and Measurements states, "This work indicates that given the sources of uncertainties considered here, together with an allowance for unspecified uncertainties, the values of the lifetime risk can range from about one-fourth or so to about twice the nominal values" (DIRS 101884-NCRP 1997, p. 75).

Because of the large uncertainties that exist in the dose/effect relationship, the Health Physics Society has recommended "…against quantitative estimation of health risks due to radiation exposure below a lifetime dose of 10 rem …" (DIRS 101835-Mossman et al. 1996, p. 1). In essence, the Society has recommended against the quantification of risks due to individual radiation exposures comparable to those estimated in the No-Action analysis. These uncertainties are due, in part, to the fact that epidemiological studies have been unable to demonstrate that adverse health effects have occurred in individuals exposed to small doses (less than 10 rem per year) over a period of many years (chronic exposures) and to the fact that the extent to which cellular repair mechanisms reduce the likelihood of cancers is unknown.

Other areas of uncertainty in estimation of dose and risk include the following:

- *Uncertainties Related to Plant and Human Uptake of Radionuclides.* There are large uncertainties related to the uptake (absorption) of radionuclides by agricultural plants, particularly in the case where "regionalized," versus "site-specific" data are used. Also of importance are variations in the absorption of specific radionuclides through the human gastrointestinal tract. Factors that influence the absorption of radionuclides include their chemical or physical form, their concentrations, and the presence of stable elements having similar chemical properties. In the case of agricultural crops, many of these factors are site-specific.

- *Uncertainties in Dose and Risk Conversion Factors.* The magnitudes and sources of the uncertainties in the various input parameters for the analytical models need to be recognized. In addition to the factors cited above, these include those required for converting absorbed doses into equivalent doses, for calculating committed doses, and for converting organ doses into effective (whole body) doses. Although these various factors are commonly assigned point values for purposes of dose and risk estimates, each of these factors has associated uncertainties.

- *Conservatisms in Various Models and Parameters.* In addition to recognizing uncertainties, one must take into account the magnitudes and sources of the conservatisms in the parameters and models being used. These include the fact that the values of the tissue weighting factors and the methods for calculating committed and collective doses are based on the assumption of a linear no-threshold relationship between dose and effect. As the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements have stated, the use of the linear no-threshold hypothesis provides an upper bound on the associated risk (DIRS 147927-ICRP 1966, p. 56). Also to be considered is that the concept of committed dose could overestimate the actual dose by a factor of 2 or more (DIRS 101856-NCRP 1993, p. 25).

K.4.3.3 Accidents and Their Uncertainty

The accident methodology used in this analysis is described in Section K.2.5 for Scenarios 1 and 2. It states that for Scenario 1 an aircraft crash into the storage array would provide the most severe accident scenario and its consequences would not cause a release from the rugged concrete storage module. The analysis placed considerable weight on the quality and strength of the concrete storage module and dry storage canister. For an analysis extending 10,000 years, more severe natural events can be postulated than those used as the design basis for the dry storage canister, and they could cause failure of the canister. This could exceed the consequences estimated for Scenario 1, but it would be unlikely to exceed the consequences for the aircraft accident scenario evaluated for Scenario 2.

Section K.2.5.1 concludes that the aircraft crash on the degraded concrete storage modules would be the largest credible event that could occur. The best estimate impacts from this event ranged from 3 latent cancer fatalities for a low-population site to 13 for a high-population site. The uncertainties in these estimates are very large. As discussed above, the aircraft crash could cause a minimum of no latent cancer fatalities given the uncertainty in the model that converts doses to cancers. The maximum impact could be substantially greater than the estimated values if an aircraft crash involving the largest commercial jet occurred at the time of initial concrete storage module degradation at a specific site under adverse weather conditions (conditions that would maximize the offsite doses) involving spent fuel with the maximum expected inventory of radionuclides.

K.4.4 UNCERTAINTY SUMMARY

The sections above discuss qualitatively and semiquantitatively the uncertainties associated with impact estimates resulting from the long-term storage of spent nuclear fuel and high-level radioactive waste at multiple sites across the United States. As stated above, DOE has not attempted to quantify the variability of estimated impacts related to possible changes in climate, societal values, technology, or future lifestyles. Although uncertainties with these changes could undoubtedly affect the total consequences reported in Section K.3 by several orders of magnitude, DOE did not attempt to quantify these uncertainties to simplify the analysis.

DOE attempted to quantify a range of uncertainties associated with mathematical models and input data, and estimated the potential effect these uncertainties could have on collective human health impacts. By summing the uncertainties discussed in Sections K.4.1, K.4.2, and K.4.3 where appropriate, DOE estimates that total collective impacts over 10,000 years could have been underestimated by as much as 3 or 4 orders of magnitude. However, because there are large uncertainties in the models used for quantifying the relationship between low doses (that is, less than 10 rem) and the accompanying health impacts, especially under conditions in which the majority of the populations would be exposed at a very low dose rate, the actual collective impact could be small.

On the other hand, impacts to individuals (human intruders) who could move to the storage sites and live close to the degraded facilities could be severe. During the early period (200 to 400 years after the assumed loss of institutional control), acute exposures to external radiation from the spent nuclear fuel and high-level radioactive waste material could result in prompt fatalities. In addition, after a few thousand years onsite shallow aquifers could be contaminated to such a degree that consumption of water from these aquifers could result in severe adverse health effects, including premature death. Uncertainties related to these localized impacts are related primarily to the inability to predict accurately how many individuals could be affected at each of the 77 sites over the 10,000-year analysis period. In addition, the uncertainties associated with localized impacts would exist for potential consequences resulting from disruptive events, both manmade and natural.

Therefore, as listed in Table K-15, uncertainties resulting from future changes in natural phenomena and human behavior that cannot be predicted, process model uncertainties, and dose-effect relationships, taken together, could produce the results presented in Section K.3, overestimating or underestimating the impacts by as much as several orders of magnitude. Uncertainties of this magnitude are typical of predictions of the outcome of complex physical and biological phenomena over long periods. However, these predictions (with their uncertainties) are valuable to the decisionmaking process because they provide insight based on the best information available.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

104597 Battelle 1998 — Battelle Pacific Northwest Division 1998. *Analytical Approach for Estimating Releases of Spent Nuclear Fuel and High-Level Waste for the Yucca Mountain Environmental Impact Statement No-Action Alternative*. Las Vegas, Nevada: Jason Technologies. ACC: MOL.19990513.0039.

101533 Buck et al. 1995 — Buck, J.W.; Whelan, G.; Droppo, J.G., Jr.; Strenge, D.L.; Castleton, K.J.; McDonald, J.P.; Sato, C.; and Streile, G.P. 1995. *Multimedia Environmental Pollutant Assessment System (MEPAS) Application Guidance, Guidelines for Evaluating MEPAS Input Parameters for Version 3.1*. PNL-10395. Richland, Washington: Pacific Northwest Laboratory. TIC: 242139.

152471 Bureau of the Census 2000 — Bureau of the Census 2000. "National Population Projections I. Summary Files." Washington, D.C.: Bureau of the Census. Accessed August 28, 2000. ACC: MOL.20010725.0152. http://www.census. gov/population/www/projections/natsum-T1.html

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101533	Buck et al. 1995	Buck, J.W.; Whelan, G.; Droppo, J.G., Jr.; Strenge, D.L.; Castleton, K.J.; McDonald, J.P.; Sato, C.; and Streile, G.P. 1995. *Multimedia Environmental Pollutant Assessment System (MEPAS) Application Guidance, Guidelines for Evaluating MEPAS Input Parameters for Version 3.1*. PNL-10395. Richland, Washington: Pacific Northwest Laboratory. TIC: 242139.
152471	Bureau of the Census 2000	Bureau of the Census 2000. "National Population Projections I. Summary Files." Washington, D.C.: Bureau of the Census. Accessed August 28, 2000. ACC: MOL.20010725.0152. http://www.census. gov/population/www/projections/natsum-T1.html

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100355	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Introduction." Chapter 1 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00001 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 19981008.0001. In the Draft EIS, this reference was cited as TRW 1998m in Appendix K.
100356	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Unsaturated Zone Hydrology Model." Chapter 2 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0002. In the Draft EIS, this reference was cited as TRW 1998n in Appendix K.
100357	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Thermal Hydrology." Chapter 3 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00003 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0003. In the Draft EIS, this reference was cited as TRW 1998o in Appendix K.
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100362	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Waste Form Degradation, Radionuclide Mobilization, and Transport Through the Engineered Barrier System." Chapter 6 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0006. In the Draft EIS, this reference was cited as TRW 1998k in Appendix K.
100364	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Unsaturated Zone Radionuclide Transport." Chapter 7 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document.* B00000000-01717-4301-00007 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0007. In the Draft EIS, this reference was cited as TRW 1998r in Appendix K.
100365	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Saturated Zone Flow and Transport." Chapter 8 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00008 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0008. In the Draft EIS, this reference was cited as TRW 1998s in Appendix K.
100366	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Biosphere." Chapter 9 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document.* B00000000-01717-4301-00009 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 19981008.0009. In the Draft EIS, this reference was cited as TRW 1998t in Appendix K.
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Appendix L

Floodplain/Wetlands Assessment for the Proposed Yucca Mountain Geologic Repository

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APPENDIX L. FLOODPLAIN/WETLANDS ASSESSMENT FOR THE PROPOSED YUCCA MOUNTAIN GEOLOGIC REPOSITORY

L.1 Introduction

Pursuant to Executive Order 11988, *Floodplain Management*, each Federal agency is required, when conducting activities in a floodplain, to take actions to reduce the risk of flood damage; minimize the impact of floods on human safety, health, and welfare; and restore and preserve the natural and beneficial values served by floodplains. Pursuant to Executive Order 11990, *Protection of Wetlands*, each Federal agency is to avoid, to the extent practicable, the destruction or modification of wetlands, and to avoid direct or indirect support of new construction in wetlands if a practicable alternative exists. Regulations issued by the U.S. Department of Energy (DOE) that implement these Executive Orders are contained in Title 10 of the Code of Federal Regulations (CFR) Part 1022, *Compliance with Floodplain/Wetlands Environmental Review Requirements*.

In 1982, Congress enacted the Nuclear Waste Policy Act in recognition of the national problem created by the accumulation of spent nuclear fuel and high-level radioactive waste at many commercial and DOE sites throughout the country. The Act recognized the Federal government's responsibility to permanently dispose of the Nation's spent nuclear fuel and high-level radioactive waste. By 1986, DOE narrowed the number of potentially acceptable geologic repository sites to three. Then in 1987, Congress amended the Act by redirecting DOE to determine the suitability of only Yucca Mountain in southern Nevada.

If, after a possible recommendation by the Secretary of Energy, the President considers the site qualified for an application to the U.S. Nuclear Regulatory Commission for a construction authorization, the President will submit a recommendation of the site to Congress. If the site designation becomes effective, the Secretary of Energy will submit to the Nuclear Regulatory Commission a License Application for a construction authorization. DOE would also select a rail corridor or a site for an intermodal transfer station, along with its associated route for heavy-haul trucks, among those considered for Nevada in the EIS. Following such a decision, additional field surveys, environmental and engineering analyses, and National Environmental Policy Act reviews would likely be needed regarding a specific rail alignment for the selected corridor. When more specific information becomes available about activities proposed to take place within floodplains and wetlands, DOE will conduct further environmental review in accordance with 10 CFR 1022.

In 1989, DOE published a Notice of Floodplain/Wetlands Involvement (54 *FR* 6318, February 9, 1989) for site characterization studies at Yucca Mountain. These studies are designed to determine the suitability of Yucca Mountain to isolate nuclear waste. A floodplain assessment was prepared (DIRS 104559-YMP 1991, all) and a Statement of Findings was issued by DOE (56 *FR* 49765, October 1, 1991). In 1992, DOE prepared a second floodplain assessment on the cumulative impacts of surface-based investigations and locating part of the Exploratory Studies Facility in the 100-year floodplain of a wash at Yucca Mountain (DIRS 103197-YMP 1992, all). The Statement of Findings for this assessment was published in the Federal Register (57 *FR* 48363, October 23, 1992). Both Statements of Findings concluded that the benefits of locating activities and structures in the floodplains outweigh the potential adverse impacts to the floodplains and that alternatives to these actions were not reasonable.

The Nuclear Waste Policy Act, as amended, requires that a recommendation by the Secretary to the President to construct a repository must be accompanied by a Final EIS. As part of the EIS process, and following the requirements of 10 CFR Part 1022, DOE issued a *Notice of Floodplain and Wetlands Involvement* in the *Federal Register* (64 *FR* 31554, June 11, 1999). The Notice requested comments from the public regarding potential impacts on floodplains and wetlands associated with construction of a potential rail line or a potential intermodal transfer station with its associated route for heavy-haul trucks to and in the vicinity of Yucca Mountain, depending on the rail or intermodal alternative selected (Figure L-1). DOE received no comments from the public. This floodplain/wetlands assessment has been prepared in conjunction with the *Notice of Floodplain and Wetlands Involvement*, and in accordance with 10 CFR Part 1022 and was made available to the public as part of the Draft EIS. Several comments were received dealing with this floodplain/wetlands assessment during the public comment period for the Draft EIS. In addition to changes driven by some of these comments, this floodplain/wetlands assessment now includes a statement of findings as Section L.7.

This assessment examines the effects of proposed repository construction and operation and potential construction of a rail line or intermodal transfer station on:

1. Floodplains near the Yucca Mountain site (Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash; there are no delineated wetlands near the Yucca Mountain site), and

2. Floodplains and areas that may have wetlands (for example, springs and riparian areas) along potential rail corridors in Nevada and at intermodal transfer station locations associated with routes for heavy-haul trucks. If DOE selects rail as the mode of spent nuclear fuel and high-level radioactive waste transport in Nevada to the Yucca Mountain site, one of five rail corridors would be selected (Figure L-2). If DOE selects heavy-haul as the mode of transport for spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site, one of five heavy-haul truck routes and one of three intermodal transfer station locations would be selected (Figure L-3). A more detailed floodplain/wetlands assessment of the selected rail corridor or route for heavy-haul trucks would then be prepared. This assessment compares what is known about the floodplains, springs, and riparian areas along the five possible rail corridors and at the three intermodal transfer station locations. This assessment does not evaluate potential floodplain or wetlands effects along heavy-haul truck routes because these existing roads should already be designed to meet 100-year floodplain design specifications. If upgrades to existing roads are deemed necessary, a more detailed floodplain/wetlands assessment would be prepared at that time.

Title 10 CFR Part 1022.4 defines a flood or flooding as "*…a temporary condition of partial or complete inundation of normally dry land areas from...the unusual and rapid accumulation of runoff of surface waters...*" Title 10 CFR Part 1022.4 identifies floodplains that must be considered in a floodplain assessment as the *base floodplain* and the *critical-action floodplain*. The base floodplain is the area inundated by a flood having a 1.0 percent chance of occurrence in any given year (referred to as the 100-year floodplain). The critical-action floodplain is the area inundated by a flood having a 0.2 percent chance of occurrence in any given year (referred to as the 500-year floodplain). *Critical action* is defined as any activity for which even a slight chance of flooding would be too great. Such actions could include the storage of highly volatile, toxic, or water-reactive materials. The critical-action floodplain was considered because petroleum, oil, lubricants, and other hazardous materials could be used during the construction of a rail line or road upgrades and because spent nuclear fuel and high-level radioactive waste would be transported across the washes.

Title 10 CFR Part 1022.11 requires DOE to use Flood Insurance Rate Maps or Flood Hazard Boundary Maps to determine if a proposed action would be located in the base or critical-action floodplain. On Federal or state lands where Flood Insurance Rate Maps or Flood Hazard Boundary Maps are not available, DOE is required to seek flood information from the appropriate land-management agency or from agencies with expertise in floodplain analysis. The U.S. Geological Survey was therefore asked by DOE to complete a flood study of Fortymile Wash and its principal tributaries (which include Busted Butte, Drill Hole, and Midway Valley washes) and outline areas of inundation from 100-year and 500-year floods (DIRS 102783-Squires and Young 1984, Plate 1).

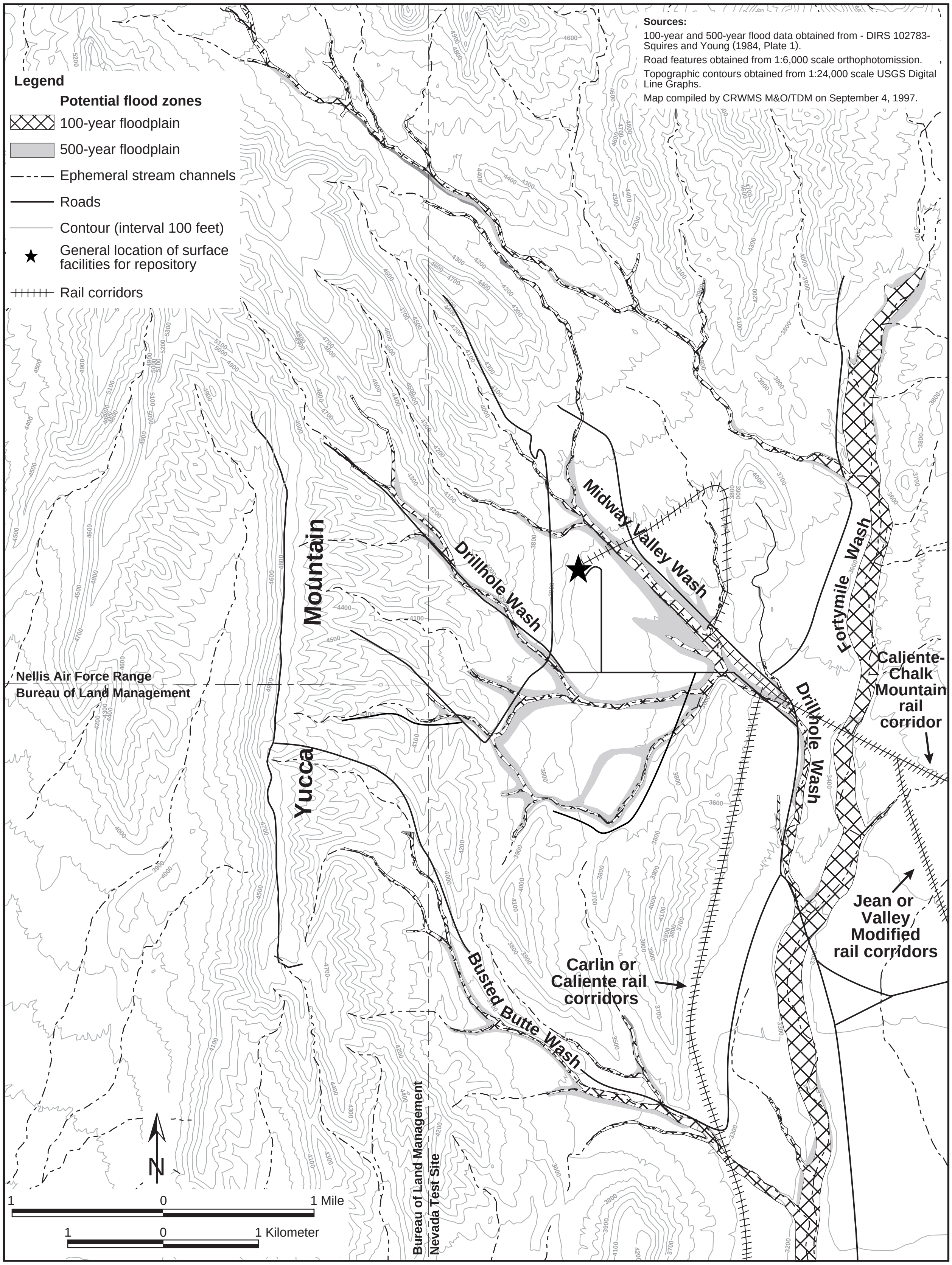

Figure L-1. Yucca Mountain site topography, floodplains, and potential rail corridors.

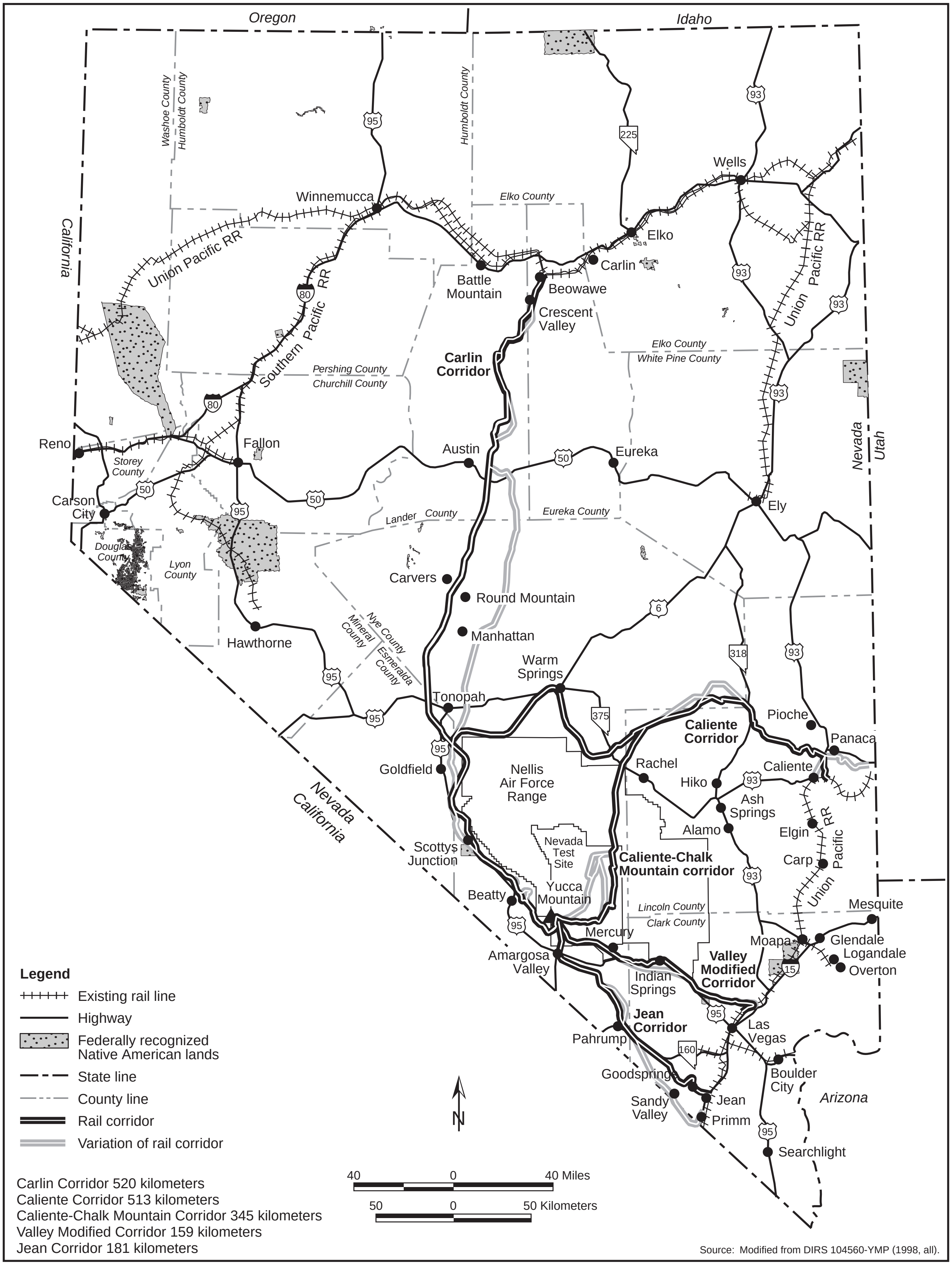

Figure L-2. Potential Nevada rail corridors to Yucca Mountain.

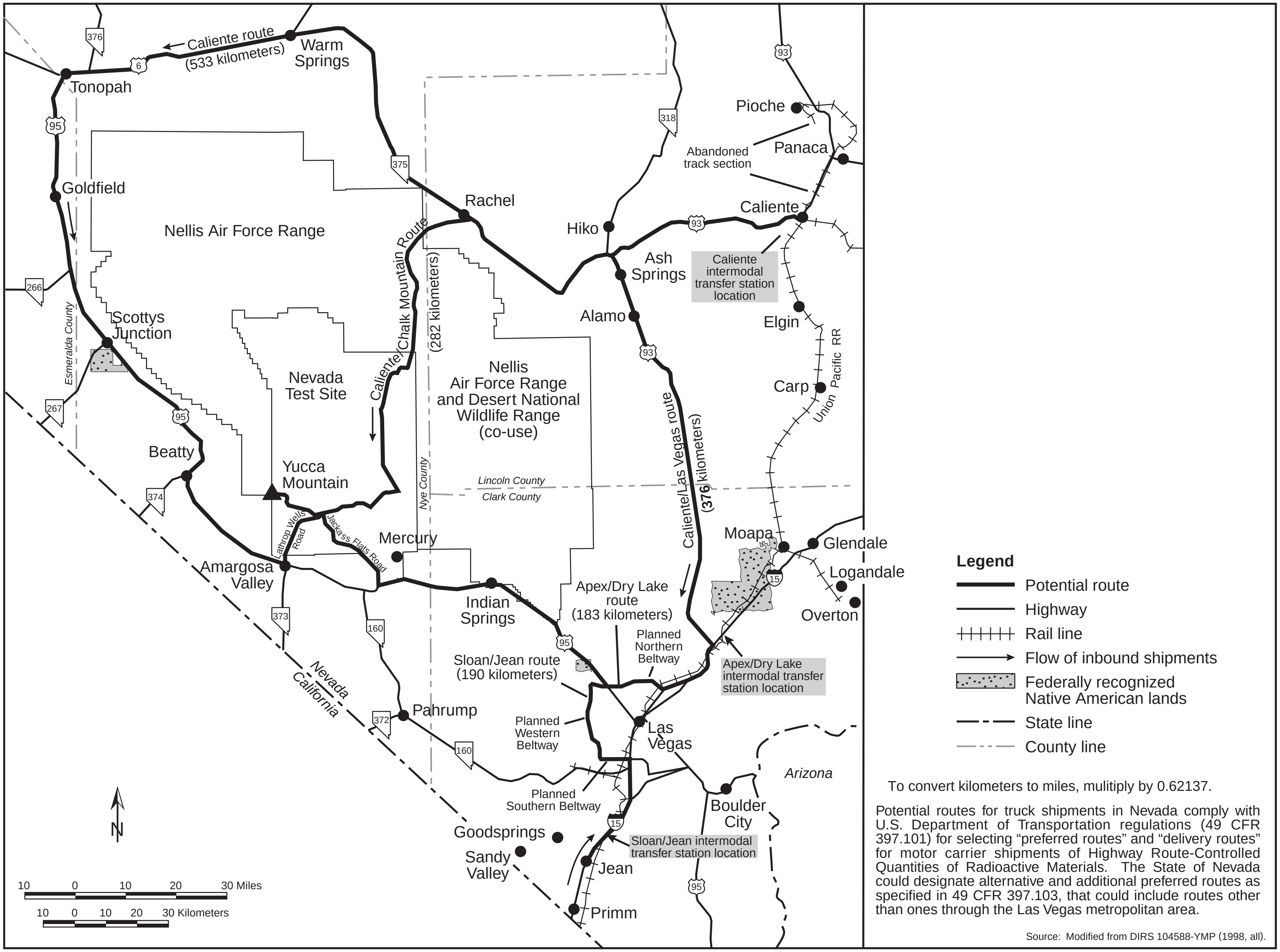

Figure L-3. Potential routes in Nevada for heavy-haul trucks.

Title 10 CFR Part 1022 also requires DOE to determine whether wetlands would be affected by the proposed action and, if necessary, to conduct a wetlands assessment. As required by 10 CFR Part 1022.11(c), DOE examined the following information with regard to possible wetlands in the vicinity of the Yucca Mountain site:

- *U.S. Fish and Wildlife Service National Wetlands Inventory.* Maps from the National Wetlands Inventory do not identify any naturally occurring wetlands in the vicinity of the Yucca Mountain site (DIRS 147930-FWS 1995, all).

- *U.S. Department of Agriculture, Soil Conservation Service Local Identification Maps.* The Soils Conservation Service (now called Natural Resource Conservation Service) has not conducted a soil survey of the Yucca Mountain site. However, DOE and other agencies have conducted comprehensive surveys and studies of soils at the Yucca Mountain site and in the surrounding area. These surveys are summarized in DIRS 104592-CRWMS M&O (1999, pp. 2 to 6). The surveys indicate that there are no naturally-occurring hydric soils at Yucca Mountain.

- *U.S. Geological Survey Topographic Maps.* Topographic maps of the vicinity (for example, DIRS 147932-USGS 1983, all) do not show springs, permanent streams, or other indications of wetlands.

- *State Wetlands Inventories.* There are no State of Nevada wetlands inventories in the vicinity of Yucca Mountain.

- *Regional or Local Government-Sponsored Wetlands or Land-Use Inventories.* DOE has conducted a wetlands inventory of the Nevada Test Site (DIRS 101833-Hansen et al. 1997, p. 1-161). The closest naturally occurring wetlands to Yucca Mountain is on the upper west slope of Fortymile Canyon, 6 kilometers (3.7 miles) north of the North Portal, outside of the proposed repository construction area. In addition, riparian vegetation occurs adjacent to four manmade well ponds east of Yucca Mountain (DIRS 104593-CRWMS M&O 1999, p. 2-14), but these are outside of areas where construction or other proposed actions would occur.

Based on this information, DOE concluded that a wetlands assessment is not required to comply with 10 CFR Part 1022.

L.2 Project Description

If Yucca Mountain is selected as a site to construct a repository, DOE would ship spent nuclear fuel and high-level radioactive waste to the site for a period of about 24 years. For analysis purposes, DOE assumed that spent nuclear fuel and high-level radioactive waste emplacement would begin in 2010. One of five candidate rail corridors leading to the site could be selected in Nevada (Figure L-2). In the vicinity of the Yucca Mountain site the five rail corridors converge to two possible routes. Alternatively, if heavy-haul transport were selected, one intermodal transfer station and one associated route would be identified from the three potential intermodal transfer station locations and five potential routes for heavy-haul trucks (Figure L-3). In the vicinity of the Yucca Mountain site, the potential routes converge to two possible routes that may require upgrades. At greater distances, routes would utilize public roads and existing Nevada Test Site roads to the extent possible.

Some transportation-related actions associated with the DOE proposal would occur in floodplains on the proposed repository site on land the Federal government would manage. Route construction and operation could affect the 100-year and 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash in the vicinity of the Yucca Mountain site. This assessment examines the potential floodplain impacts to all four washes although all four might not be affected. The effects on floodplains and areas that may contain wetlands elsewhere in Nevada along the five rail corridors and at the three intermodal station locations associated with heavy-haul transport are examined using available information. When DOE makes a decision whether to use rail or heavy-haul transport, more information would be obtained to support further environmental review.

This section is divided into two parts. Section L.2.1 discusses the proposed action in the vicinity of the Yucca Mountain site including rail access; heavy-haul truck access; and potential construction of an associated rail line, bridge, and roads. Section L.2.2 discusses possible actions elsewhere in Nevada including rail access and intermodal transfer station locations.

L.2.1 PROPOSED ACTIONS AT YUCCA MOUNTAIN

The preliminary layout of surface facilities at the repository is shown on Figure L-1. Except for a possible rail line and roads, no facilities are generally anticipated to be located within either the 100-year or 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, or Midway Valley Wash. The paragraphs below describe the rail line and roads that could affect the floodplains of these washes in the vicinity of the Yucca Mountain site.

DOE has used other flood estimating techniques to evaluate the Proposed Action at Yucca Mountain. As described in Section L.1 and shown in Figure L-1, the U.S. Geological Survey performed the flood study at Fortymile Wash and its principal tributaries that forms the basis for the 100- and 500- year flood inundation levels evaluated in this EIS. DOE used another estimating method, the *probable maximum flood* value methodology [based on American National Standards Institute and American Nuclear Society Standards for Nuclear Facilities (DIRS 103071-ANS 1992, all)], to generate maximum flood values for specific segments of washes adjacent to planned Yucca Mountain facilities (DIRS 100530-Blanton 1992, all; DIRS 108883-Bullard 1992, all). The probable maximum flood methodology is a very conservative approach intended to generate the most severe flood value reasonably possible for the location under evaluation, and is larger than any of the other flood values estimated for the site. None of the flood estimates, including those generated for a probable maximum flood, predict water levels high enough to reach the portal entrances to the subsurface facilities. Both the north and south portal entrances to the subsurface facilities were located to be above the probable maximum flood event. However, some of the surface support facilities outside the north portal (in addition to a possible rail line and roads), would be within the level of the probable maximum flood (DIRS 102215-YMP 1995, p. 2-12). DOE would design surface facilities where it would manage radiological materials to ensure their protection against this most severe flood level. The probable maximum flood approach is the method most in use around the world in hydrologic designs for structures critical to public safety, and is required for the design of dam spillways, large detention basins, major bridges, and nuclear facilities.

L.2.1.1 Rail Access

At this time, there is no rail access to the Yucca Mountain site. DOE has identified five candidate rail corridors in Nevada for transporting spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

If DOE selected a rail corridor leading to the Yucca Mountain site from the west and south (either the Carlin or Caliente Corridors), the rail line could cross Busted Butte Wash, Drill Hole Wash just west of its confluence with Fortymile Wash, and Midway Valley Wash (Figure L-1). Cut, fill, drainage culverts or bridges could be used to cross Busted Butte, Drill Hole, and Midway Valley washes. The widths of Busted Butte Wash and Drill Hole Wash (including their floodplains) are about 150 meters (500 feet) each where they would be crossed by the rail line. The width of Midway Valley Wash (including its floodplain) is about 300 meters (1,000 feet) where it could be crossed by the rail line.

If DOE selected a rail corridor leading to the Yucca Mountain site from the east (Caliente-Chalk Mountain, Jean, or Valley-Modified corridors) the rail line could cross approximately 400 meters (1,300 feet) of Fortymile Wash and its associated floodplains. In this case, the rail line could cross the wash on either a bridge (with supports located in the wash) or on a raised rail line that could be constructed in the wash (with appropriately-sized drainage culverts). After crossing Fortymile Wash, the rail line could continue along the east side of Yucca Mountain and cross about 300 meters (1,000 feet) of Midway Valley Wash before arriving at the repository.

L.2.1.2 Heavy-Haul Truck Access

DOE has identified five candidate routes for heavy-haul trucks in Nevada for transporting spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site.

If DOE selected a route leading to the Yucca Mountain site from the west and south, the route could cross Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash (Figure L-1). Cut, fill, drainage culverts or bridges could be used to cross Busted Butte, Drill Hole, and Midway Valley washes.

If DOE selected a route leading to the Yucca Mountain site from the east, the route could cross Fortymile Wash. The route could either cross through the wash or a bridge could be constructed over it. After crossing Fortymile Wash, the route could continue along the east side of Yucca Mountain and could cross Midway Valley Wash before arriving at the repository.

During potential repository operation, some spent nuclear fuel and high-level radioactive waste would be transported to the Yucca Mountain site by legal-weight trucks. These trucks could access Yucca Mountain from the east by crossing Fortymile Wash along the existing road or access Yucca Mountain along the route used by heavy-haul trucks. The legal-weight trucks could then proceed along the east side of Yucca Mountain and cross Midway Valley Wash along the route.

L.2.1.3 Construction

Construction of a candidate rail line near Yucca Mountain as well as upgrading the existing roads for heavy-haul and legal-weight trucks and for access to site facilities in the vicinity would take about 1 year to complete. Existing site roads would be upgraded as needed to provide access between site facilities, including ventilation shafts that would be located to the west of the portal areas. In some cases, new road segments would be necessary to provide the access. The site access roads could go through drainage channels, primarily upper portions of Drill Hole Wash and one of its tributaries to the south (see Figure L-1). Standard construction practices would be used, including the use of explosives and heavy earth-moving equipment. Standard measures would also be used to minimize erosion. Petroleum fuels, oils, lubricants and other hazardous materials would be used during construction, although these materials would be stored outside the 500-year floodplain.

Construction aggregate could be obtained from local borrow pits, but rail-bed ballast would need to be obtained from outside sources. Concrete would be obtained from a nearby concrete batch plant or from a new batch plant that may be built closer to the repository site. Neither the borrow pits nor the concrete batch plant would be located in a floodplain or wetlands. Rock excavated from the subsurface would be stockpiled in the area between the North and South Portals, just south of the primary channel of Drill Hole Wash. The stockpiled rock would be in the area of 100 and 500 year flood zones for a southern tributary to Drill Hole Wash (see Figure L-1).

If DOE decided to build a bridge at the 300- to 450-meter (1,000- to 1,500-foot)-wide Fortymile Wash, it would perform a flood design analysis to determine the optimum span of the structure. Supports for the bridge would be constructed in the floodplain of the wash. If a rail line were constructed across the bottom of Fortymile Wash, extensive earthwork (cut and fill) would be required to maintain the less-than-2-percent grade required for the rail alignment.

L.2.2 POSSIBLE ACTIONS ELSEWHERE IN NEVADA

At this time there is no rail access to Yucca Mountain. This means that material traveling by rail would have to continue to the repository on a new branch rail line or transfer to heavy-haul trucks at an intermodal transfer station in Nevada and then travel on existing highways. DOE is considering construction of *either* a new branch rail line *or* an intermodal transfer station and associated highway improvements. The DOE has identified five candidate rail corridors, each of which has alignment variations (Figure L-2), and three possible locations for an intermodal transfer station associated with heavy-haul trucks (Figure L-3).

For analytical purposes, it is assumed that construction of a rail line in Nevada would take between 40 and 46 months. If a decision were made to proceed with development of a repository, it is likely that the DOE would decide at that time whether to build a rail line or to develop an intermodal transfer station site for heavy-haul waste transport. Should DOE decide to construct a rail line, standard practices for construction of rail lines would be used, including minimizing steep grades, utilizing cut and fill earthwork techniques, and crossing flood-prone areas using culverts or bridges. With respect to flood-prone areas, DOE would generally design rail line features to accommodate 100-year flood levels. However, the final design would be in accordance with standard engineering practices and judgment and economic analysis. The design process would consider a range of flood frequencies and include a cost benefit analysis in the selection of a design frequency (DIRS 106860-AREA 1997, Volume 1, Section 3.3.2.c). Should DOE decide to use a route for heavy-haul trucks, portions of the existing roads used for heavy-haul transport may require upgrades to accommodate the heavy loads.

L.3 Existing Environment

L.3.1 EXISTING ENVIRONMENT AT YUCCA MOUNTAIN

Fortymile Wash is about 150 kilometers (93 miles) long and drains an area of about 810 square kilometers (310 square miles) to the east and north of Yucca Mountain (Figure L-1). The wash continues southward and connects to the Amargosa River. The Amargosa River drains an area of about 8,000 square kilometers (3,100 square miles) by the time it reaches Tecopa, California. The mostly-dry river bed extends another 100 kilometers (60 miles) before ending in Death Valley.

Busted Butte and Drill Hole washes drain the east side of Yucca Mountain and flow into Fortymile Wash (Figure L-1; Midway Valley Wash is a tributary to Drill Hole Wash). Busted Butte Wash drains an area of 17 square kilometers (6.6 square miles) and Drill Hole Wash drains an area of 40 square kilometers (15 square miles).

The existing environment at and near Yucca Mountain, including Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash is described in Chapter 3 of the EIS. The information below summarizes several of the more important aspects of the environment that pertain to this floodplain assessment.

L.3.1.1 Flooding

Water flow in the four washes is rare. The arid climate and meager precipitation [about 10 to 25 centimeters (4 to 10 inches) per year at Yucca Mountain] result in quick percolation of surface water into the ground and rapid evaporation. Flash floods, however, can occur after unusually strong summer thunderstorms or during sustained winter precipitation. During these times, runoff from ridges, pediments, and alluvial fans flows into the normally dry washes that are tributary to Fortymile Wash. Estimated peak discharges in Fortymile Wash are 340 cubic meters per second (12,000 cubic feet per second) for the 100-year flood and 1,600 cubic meters per second (58,000 cubic feet per second) for the 500-year flood. Estimated peak discharges in Busted Butte Wash are 40 cubic meters per second (1,400 cubic feet per second) for the 100-year flood and 180 cubic meters per second (6,500 cubic feet per second) for the 500-year flood. Estimated peak discharges in Drill Hole Wash are 65 cubic meters per second (2,300 cubic feet per second) for the 100-year flood and 280 cubic meters per second (10,000 cubic feet per second) for the 500-year flood.

The Nevada Test Site access road to Yucca Mountain crosses Fortymile Wash in the area where it joins Drill Hole Wash. The next nearest manmade structure within Fortymile Wash is U.S. Highway 95, more than 19 kilometers (12 miles) south of the confluence of Drill Hole and Fortymile washes. The portion of the community of Amargosa Valley that was once known as Lathrop Wells is the nearest population center to Yucca Mountain, about 22 kilometers (14 miles) to the south along U.S. 95 and 3.2 kilometers (2 miles) east of Fortymile Wash.

Flooding events in the region are often very localized. A flash flood in one or more of the washes draining to Fortymile Wash, for example, might not result in any notable flow in the much larger Fortymile Wash. In rare cases, however, storm and runoff conditions can be extensive enough to result in flow being present throughout the drainage system. DIRS 155679-Glancy and Beck (1998, all) documented conditions during March 1995 and February 1998 where Fortymile Wash and the Amargosa River flowed simultaneously through their primary channels to Death Valley. The 1995 incident represented the first documented case of this flow condition.

L.3.1.2 Wetlands

There are no springs, perennial streams, hydric soils, or naturally occurring wetlands at Yucca Mountain. There are two manmade well ponds within Fortymile Wash, and two east of that wash, that have riparian vegetation (DIRS 104592-CRWMS M&O 1999, pp. 5 to 6; DIRS 104593-CRWMS M&O 1999, p. 2-14).

L.3.1.3 Biology

Vegetation at and near Fortymile Wash is typical of the Mojave Desert. The mix or association of vegetation in Fortymile Wash, which is dominated by the shrubs white bursage (*Ambrosia dumosa*), creosotebush (*Larrea tridentata*), white burrobush (*Hymenoclea salsola*), and heathgoldenrod (*Ericameria paniculata*), differs somewhat from other vegetation association at Yucca Mountain (DIRS 104589-CRWMS M&O 1998, pp. 5 to 7). No plant species are known to be restricted to the floodplains. In addition, none of the more than 180 plant species known to occur at Yucca Mountain is endemic to the area.

None of the 36 mammal, 27 reptile, or 120 bird species that have been documented at Yucca Mountain are restricted to or dependent on the floodplain. These species all are widespread throughout the region. No amphibians have been found at Yucca Mountain.

The only plant or animal species that has been found at Yucca Mountain that is classified as threatened, endangered, or proposed under the Endangered Species Act is the desert tortoise (*Gopherus agassizii*) which is classified as threatened. Yucca Mountain is at the northern edge of the range of the desert tortoise (DIRS 101915-Rautenstrauch, Brown, and Goodwin 1994, p. 11). Desert tortoises are known to occur within the floodplain of Fortymile Wash, but their abundance there and elsewhere at Yucca Mountain is low compared to other parts of its range farther south and east (DIRS 102869-CRWMS M&O 1997, pp. 6 to 11). Information on the ecology of the desert tortoise population at Yucca Mountain is summarized in DIRS 104593-CRWMS M&O (1999, p. 2-8).

Four species classified as sensitive by the Bureau of Land Management occur at Yucca Mountain: two species of bats [the long-legged myotis (*Myotis volans*) and the fringed myotis (*Myotis thysanodes*)] (DIRS 104590-CRWMS M&O 1998, p. 11), the western chuckwalla (*Sauromalus obesus obesus*) (DIRS 103159-CRWMS M&O 1998, pp. 22 to 23), and the western burrowing owl (*Speotyto cunicularia hypugaea*) (DIRS 103654-Steen et al. 1997, pp. 19 to 29). These species may occur within the floodplain of Fortymile Wash, but they are not dependent upon habitat there (DIRS 104590-CRWMS M&O 1998, p. 8; DIRS 103159-CRWMS M&O 1998, pp. 22 to 23; DIRS 103654-Steen et al. 1997, pp. 19 to 29).

L.3.1.4 Archaeology

Archaeological surveys have been conducted in Fortymile Wash east of Yucca Mountain. Fortymile Wash was an important crossroad where several trails converged from such distant places as Owens Valley, Death Valley, and the Avawtz Mountains.

L.3.2 EXISTING ENVIRONMENT ELSEWHERE IN NEVADA

The following sections describe the environment along each of the five candidate rail corridors (Figure L-2) and at the three intermodal transfer station locations (Figure L-3). The corridors are about 0.4 kilometer (0.25 mile) wide, and the length of each corridor varies (Table L-1). Table L-2 lists surface-water-related resources along each of the five rail corridors. Table L-3 lists similar information for the corridor variations. The last column of Table L-2 identifies water resources that DOE would avoid by using a specified variation rather than the corresponding section of the corridor. Water resources along the variation that would be "substituted" can be linked from Table L-3. If the same water resource would be close to both the corridor and its variation, it is listed as "Avoided" in Table L-2, but appears in Table L-3 for the variation. Details of each of the corridors and surface-water-related resources are found in DIRS 104593-CRWMS M&O (1999, Appendixes E, F, G, H, and I).

Table L-1. Length of each rail corridor implementing alternative.

Rail corridor	Length	Range with variations
Caliente	513 kilometers (319 miles)	512 to 853 kilometers (318 to 344 miles)
Carlin	520 kilometers (323 miles)	414 to 544 kilometers (257 to 338 miles)
Caliente-Chalk Mountain	345 kilometers (214 miles)	344 to 382 kilometers (214 to 237 miles)
Jean	181 kilometers (112 miles)	181 to 204 kilometers (112 to 127 miles)
Valley Modified	159 kilometers (98 miles)	159 to 163 kilometers (99 to 101 miles)

Table L-4 lists identified 100-year flood zones associated with each rail corridor. The information in this table is from Flood Insurance Rate Maps published by the Federal Emergency Management Agency for Clark, Eureka, Lander, Lincoln, and Nye Counties, Nevada. DOE plotted positions of the rail corridors on the flood maps noting the 100-year flood zones intersected by the corridor centerline and scaling crossing distances. In many cases a single entry in the table represents more than one flood zone encountered in the same general area (for example, in an area of converging drainage channels). As appropriate, the description in the table under the Flood Zone Feature column identifies the inclusion of more than one zone. The last column of Table L-4 identifies if one of the variations along the corridor avoids the specific feature. If it can be avoided (as indicated by a Yes or "Y" in the column), a designation refers to the variation listing in Table L-5. As applicable, the variations in Table L-5 list the flood zones they would cross. In some cases, a flood zone avoided along the corridor would still be crossed at a different location by a variation, and appears on both tables. As indicated in a footnote to Table L-4, the Federal Emergency Management Agency has not published flood maps for all the areas crossed by the rail corridors; the table lists an estimate of the amount of each corridor that is not covered. It does not list Fortymile Wash and other drainage channels near the site of the proposed repository,

Table L-2. Surface-water-related resources along candidate rail corridors[a] (page 1 of 2).

Rail corridor	Distance from corridor (kilometers)[b]	Feature	Avoided by variation[c] (Yes or No)
Caliente, Eccles Option			
Eccles Siding to Meadow Valley Wash	Within	Riparian area/stream – corridor crosses and is adjacent to stream and riparian area in Meadow Valley Wash	Y-1, 2
Meadow Valley to Sand Spring Valley	1.0	Spring – Bennett Spring, 3.2 kilometers southeast of Bennett Pass	N
	0.05 - 2.6	Springs – group of five springs (Deadman, Coal, Black Rock, Hamilton, and one unnamed) east of White River	N
	Within	Riparian/river – corridor parallels (and crosses) the White River for about 10 kilometers. August 1997 survey found river to be mostly underground with ephemeral washes above ground.	N
	0.8	Spring – McCutchen Spring, north of Worthington Mountains	N
Sand Spring Valley to Mud Lake	0.02	Spring – Black Spring, south of Warm Springs	N
Mud Lake to Yucca Mountain	Within - 2.5	Springs – numerous springs and seeps along Amargosa River in Oasis Valley	Y-8
	Within - 0.3	Riparian Area/stream – designated area east of Oasis Valley, flowing into Amargosa River, also riparian area, with persistent water and extensive wet meadows near springs and seeps	Y-8
	0.3 - 1.3	Springs – group of 13 unnamed springs in Oasis Valley north of Beatty	Y-8
Carlin, Big Smoky Valley Option			
Beowawe *to Austin*	0.5	Spring – Tub Spring, northeast of Red Mountain	Y-11
	0.8	Spring – Red Mountain Spring, east of Red Mountain	Y-11
	0.9	Spring – Summit Spring, west of corridor and south of Red Mountain	N
	0.4	Spring – Dry Canyon Spring, west of Hot Springs Point	N
	0.8	Spring – unnamed spring on eastern slope of Toiyabe Range, southwest of Hot Springs Point	N
	1.0	Riparian area – intermittent riparian area associated with Rosebush Creek, in western Grass Valley, north of Mount Callaghan	Y-12
	Within	Riparian/creek – corridor crosses Skull Creek, portions of which have been designated riparian areas	Y-12
	Within	Riparian/creek – corridor crosses intermittent Ox Corral Creek; portions designated as riparian habitat. August, 1997 survey found creek dry with no riparian vegetation present	Y-12

Table L-2. Surface-water-related resources along candidate rail corridors[a] (page 2 of 2).

Rail corridor	Distance from corridor (kilometers)[b]	Feature	Avoided by variation[c] (Yes or No)
Beowawe to Austin (continued)	0.1	Spring – Rye Patch Spring, at north entrance of Rye Patch Canyon, west of Bates Mountain	N
	Within	Riparian area – corridor crosses and parallels riparian area in Rye Patch Canyon	Y-13
	0.7	Spring – Bullrush Spring, east of Rye Patch Canyon	N
Austin to Mud Lake	0.8	Springs – group of 35 unnamed springs, about 25 kilometers north of Round Mountain on east side of Big Smokey Valley	Y-14
	0.6	Riparian area – marsh area formed from group of 35 springs	Y-14
	0.6	Spring – Mustang Spring, south of Seyler Reservoir	Y-14
	0.3	Riparian/reservoir – Seyler Reservoir (seasonal), west of Manhattan	Y-14
Mud Lake to Yucca Mountain		See Caliente Corridor	
Caliente-Chalk Mountain			
Eccles Siding to Meadow Valley		See Caliente Corridor	
Meadow Valley to Sand Spring Valley		See Caliente Corridor	
Sand Spring Valley to Yucca Mountain	1.0	Spring – Reitman's Seep, in eastern Yucca Flat, east of BJ Wye	Y-15, 16
	0.3	Spring – Cane Spring, on north side of Skull Mountain on Nevada Test Site	Y-15
Jean, Wilson Pass Option		None identified	
Valley Modified		None identified	

a. Source: DIRS 104593-CRWMS M&O (1999, Appendixes E, F, G, H, and I).
b. To convert kilometers to miles, multiply by 0.62137.
c. Certain water resources would be avoided by variations. These are identified with a "Y" (yes) and a number representing the specific variation from Table L-3 that avoids the specific resource. Table L-3 identifies the variation by number and shows the water resources associated with each. The same water resource may be in proximity to both the corridor and variation. In such cases, the resource is marked "Avoided" for the corridor here, but will appear on Table L-3 for the variation.

discussed earlier in this document. This is because those washes near the proposed repository site are on the Nevada Test Site, one of the areas not covered by published flood maps.

More detail on each of the rail corridors is provided in Chapter 2, Section 2.1.3.3.2, and Chapter 3, Section 3.2.2. Chapter 6, Section 6.3.2, describes the potential impacts of rail implementing alternatives and Chapter 6, Section 6.3.3 describes the potential impacts of the construction and use of intermodal transfer stations under the heavy-haul truck implementing alternatives.

L.3.2.1 Caliente Corridor

Flooding: The Caliente Corridor, Eccles Option, crosses 352 washes en route to the Yucca Mountain site (DIRS 154961-CRWMS M&O 1998, all). Approximately 12 washes along this route are large enough that bridges would be required to cross them. Based on available Federal Emergency Management Agency flood maps, this corridor would cross nine different 100-year flood zones or flood-zone groups (see Table L-4) between its beginning near Caliente and when it enters the Nevada Test Site. None of the variations applicable to this corridor (Table L-5) would change this number notably. Use of the Crestline

Table L-3. Surface-water-related resources along variations for the rail corridors[a,b] (page 1 of 2).

Variation	Applicable corridor(s)[c]	Distance from corridor (kilometers)[d]	Description
1. Crestline Option	CL/CM	0.3	Spring - Miller Spring south of SR 319 and southeast of Panaca; important water source of game
		1.0	Spring - Miser Spring south of SR 319 and southeast of Panaca
		In	Riparian area/stream - variation crosses Meadow Valley Wash stream and riparian area south of Panaca
2. Caliente Option	CL/CM	In	Riparian area/stream - variation crosses Meadow Valley Wash stream and riparian area south of Caliente
		0.6	Spring - unnamed spring in Caliente
		In	Spring - unnamed spring in Meadow Valley north of Caliente
		0.5	Springs - two unnamed springs in Meadow Valley north of Caliente
3. White River Alternate	CL/CM		None identified - parallels White River further than rail corridor, but not within 1 kilometer
4. Garden Valley Alternate	CL/CM		None identified
5. Mud Lake Alternate	CL/CR		None identified
6. Goldfield Alternate	CL/CR	0.6	Spring - Tognoni Springs northeast of Goldfield
		0.4	Spring - unnamed spring south of Mud Lake and east of U.S. 95
7. Bonnie Claire Alternate	CL/CR		None identified
8. Oasis Valley Alternate	CL/CR	0.5 - 3.0	Springs - numerous springs and seeps along Amargosa River in Oasis Valley
		In - 0.3	Riparian area - designated area east of Oasis Valley, flowing into Amargosa River, also a riparian area, with persistent water and extensive wet meadows near springs and seeps
		0.8 - 1.8	Springs - group of 13 unnamed springs in Oasis Valley north of Beatty
9. Beatty Wash Alternate	CL/CR		None identified
10. Crescent Valley Alternate	CR		None identified
11. Wood Spring Canyon Alternate	CR		None identified
12. Steiner Creek Alternate	CR	In	Riparian area - variation crosses designated riparian area in Water Canyon northeast of Bates Mountain
		In	Riparian/creek - variation crosses Steiner Creek, a designated riparian area. An August 1997 survey found creek dry and lacking riparian vegetation.
13. Rye Patch Alternate	CR	0.1	Riparian area - variation parallels riparian area in Rye Patch Canyon Spring - Bull rush Spring, east of Rye Patch Canyon

Table L-3. Surface-water-related resources along variations for the rail corridors[a,b] (page 2 of 2).

Variation	Applicable corridor(s)[c]	Distance from corridor (kilometers)[d]	Description
14. Monitor Valley Option	CR	0.7	Spring - unnamed spring east of variation and east of Toquima Range
		0.2	Riparian area - designated riparian area west of variation, northwest of Belmont. An August 1997 survey found area dry and lacking riparian vegetation.
15. Topopah Option	CM	0.6	Spring – Whiterock Spring north of variation, south of Burnt Mountain
15a. Area 4 Alternate	CM		None identified – avoids Whiterock Spring of the Topopah Option
15b. Mine Mountain Alternate	CM		None identified – main portion of option still passes Whiterock Spring
16. Mercury Highway Option	CM		None identified
17. Pahrump Valley Alternate	J		None identified
18. Stateline Pass Option	J		None identified
19. Valley Connection	VM		None identified
20. Sheep Mountain Alternate	VM		None identified
21. Indian Hills Alternate	VM		None identified

a. Source: DIRS 104593-CRWMS M&O (1999, Appendixes E, F, G, H, and I).
b. Rail corridors are identified in Table L-2. Water resources identified in that table that can be avoided by a variation are identified with a number designation which is consistent with the numbering in this table.
c. Rail corridor abbreviations used in the table are defined as follows: CL = Caliente; CM = Caliente-Chalk Mountain; CR = Carlin; J = Jean; and VM = Valley Modified.
d. To convert kilometers to miles, multiply by 0.62137.

Option (number 1 in Table L-5) would decrease the number of flood zones crossed by one, and the other applicable variations would leave the number unchanged or increased by one. As noted in Table L-4, flood map coverage of the Lincoln County portion of this corridor is limited. Additional floodplain definition has not occurred.

Wetlands: At least four springs or groups of springs and three streams or riparian areas that may have associated wetlands are within 0.4 kilometer (0.25 mile) of the Caliente Corridor. However, no field searches or formal delineations of wetlands have been conducted along this route. Black Spring is near the corridor at the north end of the Kawich Range and an unnamed spring is near the corridor at the north end of the North Pahroc Range. A group of springs is in the corridor near the Amargosa River in Oasis Valley. The corridor crosses the Meadow Valley Wash south of Panaca. The corridor also crosses the White River between U.S. Highway 93 and Sand Spring Valley and parallels the river for approximately 10 kilometers (6 miles). That portion of the White River normally is dry. The corridor crosses the Amargosa River in the north end of the Oasis Valley, in an area designated as riparian area by the Bureau of Land Management (DIRS 104593-CRWMS M&O 1999, p. 3-23). Four of the variation segments (Crestline Option, Caliente Option, Goldfield Alternate, and Oasis Valley Alternate) along the Caliente Corridor would affect the number of, or distance to, associated water resources. Using the Crestline Option, Caliente Option, or Goldfield Alternate would add one spring within 0.4 kilometer (0.25 mile) of the corridor. The Oasis Valley Alternate is close to the same water resources as the corresponding portion of the Caliente Corridor, but it would be farther from two groups of springs near the Amargosa River.

Biology: The desert tortoise is the only threatened or endangered species found along the Caliente Corridor. The southern 50 kilometers (30 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (DIRS 104593-CRWMS M&O 1999, p. 3-23). Southwestern willow flycatchers (*Empidonax traillii extimus*), an

Table L-4. 100-year flood zones crossed by candidate rail corridors[a] (page 1 of 2).

Rail corridor and segment[b]	Crossing distance (kilometers)[c]	Flood zone feature(s)	Avoided by variation[d] (Yes or No)
Caliente, Eccles Option			
Eccles Siding to Meadow Valley Wash	0.2[e]	Clover Creek (intermittent)	Y-1
	0.8[e]	Meadow Valley Wash (wet)	Y-1,2
Meadow Valley Wash to Sand Spring Valley	0.5[e]	White River (intermittent)	N
Sand Spring Valley to Mud Lake	1.1	Unnamed drainage gully in East/Central Nye County; crosses twice (dry)	N
	17.5	Mud Lake basin and drainage tributaries (normally dry)	N
Mud Lake to Yucca	0.8	Unnamed washes to the north and south of Ralston (dry)	N
Mountain	0.3	Tolicha Wash	Y-7
	1.1	Amargosa River (wet in sections, intermittent in others)	Y-8
	0.1	Beatty Wash	Y-9
Carlin, Big Smoky Valley Option			
Beowawe to Austin	4.0	Flood zone associated with Coyote Creek drainage (dry)	N
	1.6	Indian Creek (dry) and unnamed wash to the south	Y-10
	0.9	Unnamed Callaghan tributary, Skull and Callaghan Creeks (intermittent)	Y-12
	0.1	Rye Patch Canyon Creek (intermittent)	Y-13,14
	1.4	Simpson Park Canyon Creek (intermittent) and Canyon Creek drainage (intermittent)	Y-13,14
	1.4	Canyon Creek and Canyon Creek drainage (intermittent)	Y-14
Austin to Mud Lake	0.3	Peavine Creek tributary (intermittent)	Y-14
Mud Lake to Yucca Mountain		See Caliente Corridor	
Caliente-Chalk Mountain			
Eccles Siding to Meadow Valley to Sand Spring Valley		See Caliente Corridor	
Sand Spring Valley to Yucca Mountain	--[f]	Not available	
Jean,[d] Wilson Pass Option			
Jean to Yucca Mountain	0.6	Three tributaries leading to Roach Lake (intermittent)	Y-18
	0.7	Lovell Wash with drainage (intermittent)	Y-18
	0.4	Two unnamed washes northwest of Lovell Wash	N
	4.1	Peak Springs Alluvial Fan (dry)	N
	1.9	Wheeler Wash (dry)	N
	0.3	Wash drainage leading to Alkali Flats (dry)	N
	0.1	Rock Valley Wash (intermittent)	N

Table L-4. 100-year flood zones crossed by candidate rail corridors[a] (page 2 of 2).

Rail corridor and segment[b]	Crossing distance (kilometers)[c]	Flood zone feature(s)	Avoided by variation[d] (Yes or No)
Valley Modified			
Dry Lake to Yucca Mountain	0.1[f]	Unnamed creek northwest of the City of Las Vegas (intermittent)	N
	1.2[e]	Drainage (projected) west of Indian Springs Air Force Auxiliary Base (intermittent)	Y-21

a. Sources:
   1. Federal Emergency Management Agency Flood Insurance Rate Maps for Clark, Eureka, Lander, Lincoln, and Nye Counties, Nevada.
   2. DIRS 154961-CRWMS M&O (1998, all).

b. Percentage of missing rail corridor information.
   1. *Caliente* - About 47 percent not available on Federal Emergency Management Agency maps, mostly due to limited coverage in Lincoln County and the Nevada Test Site.
   2. *Carlin* - About 17 percent is not available on Federal Emergency Management Agency maps, mostly due to limited coverage in Esmeralda County and Nevada Test Site.
   3. *Caliente-Chalk Mountain* – About 91 percent is not available on Federal Emergency Management Agency maps, mostly due to limited coverage in Lincoln County, the Nellis Air Force Range, and the Nevada Test Site.
   4. *Jean* - About 10 percent is not available on Federal Emergency Management Agency maps due to the portion of the route in the Nevada Test Site.
   5. *Valley Modified* - Approximately 25 percent is not available on Federal Emergency Management Agency maps due to the portion of the route in the Nellis Air Force Range, and the Nevada Test Site.

c. To convert kilometers to miles, multiply by 0.62137.

d. Certain 100-year flood zones can be avoided by corridor variations. These are identified with a "Y" (yes) and a number representing the specific variation(s) from Table L-5 that avoids the specific flood zone. The same flood zone may be crossed by both the rail corridor and a variation at different locations. In such cases, the feature will be marked "Avoided" for the rail corridor here, but will appear again on Table L-5 for the variation.

e. Projected from limited data. Specific area not covered by Federal Emergency Management Agency maps; values were extrapolated from the closest maps.

f. Limited information due to the Nevada Test Site and/or the Nellis Air Force Range.

endangered species, have been observed in dense stands of riparian vegetation in Lincoln County, but there is no suitable habitat for this species in the corridor (DIRS 152511-Brocoum 2000, pp. A-9 to A-13). Three other species (Meadow Valley Wash speckled dace [*Rhinichthys osculus* ssp.], Meadow Valley Wash desert sucker [*Catostomus clarki* ssp.], and Nevada sanddune beardtongue) classified as sensitive by the Bureau of Land Management or as protected by Nevada have been found along the Caliente Corridor. This rail corridor crosses approximately 14 areas designated as game habitat and one area classified as waterfowl habitat (DIRS 104593-CRWMS M&O 1999, p. 3-23). Two of these species, the speckled dace and desert sucker, are restricted to the floodplain of the Meadow Valley Wash. The designated waterfowl habitat also is generally restricted to the floodplain of Meadow Valley Wash and adjacent wetlands.

Archaeology: There are 97 archaeological sites that have been recorded along the Caliente Corridor (DIRS 104997-CRWMS M&O 1999, Table 3, p. 59).

L.3.2.2 Carlin Corridor

Flooding: The Carlin Corridor, Big Smoky Valley Option, crosses 273 washes en route to the Yucca Mountain site (DIRS 154961-CRWMS M&O 1998, all). Approximately 10 washes along this route are large enough that bridges would be required to cross them. According to the Federal Emergency Management Agency flood map data summarized in Table L-4, this corridor would cross 11 different 100-year flood zones or flood zone groups before entering the Nevada Test Site. Eight of the 10 variations applicable to this corridor (see Table L-5) would change the number of flood zones crossed, but with one exception, changes would be up or down by only one. The exception would be the Monitor

Table L-5. 100-year flood zones crossed by unique segments of corridor variations[a,b] (page 1 of 2).

Variation	Corridor(s)[c]	Crossing distance (kilometers)[d]	Flood zone feature(s)
1. Crestline Option	CL/CM	0.8	Crosses Meadow Valley Wash (wet)
2. Caliente Option	CL/CM	0.8	Crosses Meadow Valley Wash (wet)
		0.2	Crosses Clover Creek (intermittent)
		0.9	Crosses Meadow Valley Wash (wet) three times, runs adjacent to Meadow Valley Wash, passes in and out of flood zone
3. White River Alternate	CL/CM	None	North of the unvaried corridor
4. Garden Valley Alternate	CL/CM	None	North of the unvaried corridor
5. Mud Lake Alternate	CL/CR	3.1	Crosses a larger amount of the Mud Lake flood zone (3.1 kilometers versus 1.8 kilometers for the unvaried corridor section)
6. Goldfield Alternate	CL/CR	None	West of unvaried corridor
7. Bonnie Claire Alternate	CL/CR	1.3	Crosses an unnamed wash south of Ralston
		0.7	Crosses Tolicha Wash (intermittent)
8. Oasis Valley Alternate	CL/CR	1.0	Crosses Amargosa River (wet in segments, intermittent in others)
9. Beatty Wash Alternate	CL/CR	0.1	Crosses Beatty Wash (intermittent)
10. Crescent Valley Alternate	CR	2.0	Crosses Indian Creek (intermittent)
		3.2	Crosses an unnamed wash to the south
11. Wood Spring Canyon Alternate	CR	None	West of the unvaried corridor
12. Steiner Creek Alternate	CR	4.9	Crosses Callaghan and Canyon Creeks (intermittent)
13. Rye Patch Alternate	CR	1.4	Crosses Canyon Creek and Canyon Creek drainage (intermittent)
14. Monitor Valley Option[e]	CR	0.6	Crosses Mosquito Creek (intermittent)
		0.5	Crosses Corcoran Creek and Meadow Creek (intermittent)
		1.5	Crosses Meadow Creek drainage (dry)
		0.6	Crosses Hunts Canyon Creek (intermittent)
		0.2	Crosses Willow Creek (intermittent)
		2.0	Crosses drainage areas approaching Mud Lake (dry)
		5.7	Crosses drainage areas approaching Mud Lake (dry)
		4.8	Crosses Mud Lake drainage (dry)
15. Topopah Option	CM	--[f]	Adjacent to Caliente-Chalk Mountain Corridor
16. Mercury Highway Option	CM	--[f]	Adjacent to Caliente-Chalk Mountain Corridor
17. Pahrump Valley Alternate	J	None	Northeast of unvaried corridor
18. Stateline Pass Option	J	0.4	Crosses two tributaries to Roach Lake (dry)
		0.8	Crosses Potasi Wash, an unnamed wash and Lovell Wash drainage
		1.1	Crosses four unnamed washes and Peak Springs Fan (intermittent)

Table L-5. 100-year flood zones crossed by unique segments of corridor variations[a,b] (page 2 of 2).

Variation	Corridor(s)[c]	Crossing distance (kilometers)[d]	Flood zone feature(s)
19. Valley Connection	VM	None	At the origin of the rail corridor
20. Sheep Mountain Alternate	VM	None	North of the rail corridor
21. Indian Hills Alternate	VM	None	South of the rail corridor

a. Sources:
   1. Federal Emergency Management Agency Flood Insurance Rate Maps for Clark, Eureka, Lander, Lincoln, and Nye Counties, Nevada.
   2. DIRS 154961-CRWMS M&O (1998, all).
b. Rail corridors are identified in Table L-4. Flood zones identified in that table that can be avoided by a variation are identified with a number designation that is consistent with the numbering in this table.
c. Rail corridor abbreviations: CL = Caliente; CM = Caliente-Chalk Mountain; CR = Carlin; J = Jean; VM = Valley Modified.
d. To convert kilometers to miles, multiply by 0.62137.
e. The Monitor Valley Option and the Goldfield Connector were combined since the flood zone crossings were approximately the same distances and the final flood zone crossing distance percentages are 8 percent for all Monitor Valley variations.
f. No information available on Federal Emergency Management Agency maps.

Valley Option (number 14 in Table L-5) which would increase the number of 100-year flood zones crossed by four. Table L-4 lists more 100-year flood zones for the Carlin Corridor than for any of the other corridors. This might be due, in part, to the fact that a large portion of the Carlin Corridor is covered by flood maps. Additional floodplain definition has not occurred.

Wetlands: There are at least three springs or groups of springs, four streams designated as riparian areas by the Bureau of Land Management, and one reservoir that may have associated wetlands within 0.4 kilometer (0.25 mile) of the Carlin Corridor. However, no field searches or formal delineations of wetlands have been conducted along this route. Rye Patch Spring is on the edge of the corridor at the south end of the Simpson Park Mountains, and a group of springs is in the corridor near the Amargosa River in Oasis Valley. Seyler Reservoir is less than 0.3 kilometer (0.2 mile) from the corridor in the south end of Big Smoky Valley. There are three riparian areas (Skull and Ox Corral creeks, and Rye Patch Canyon) along the section of the route between Beowawe and Austin at the south end of Grass Valley. Ox Corral creek, at the south end of Grass Valley, is ephemeral and has little or no riparian vegetation where the route crosses it. The corridor crosses the Amargosa River in the northern Oasis Valley, in an area designated as a riparian area by the Bureau of Land Management (DIRS 104593-CRWMS M&O 1999, pp. 3-25 to 3-26). Five of the variations (Oasis Valley, Steiner Creek, Rye Patch and Goldfield Alternates, and Monitor Valley Option) would affect the number of, or distance to, water resources along the Carlin Corridor. Changes associated with the Oasis Valley and Goldfield Alternates are covered above in the Caliente Corridor discussion. The Rye Patch Alternate would involve no changes to water resources in, or within 0.4 kilometer (0.25 mile) of, the Carlin Corridor, but would parallel the riparian area in Rye Patch Canyon rather than cross it. The Steiner Creek Alternate would avoid two riparian areas, but another two would be within this corridor variation. The Monitor Valley Option would represent a major change in the corridor but, with respect to water resources within 0.4 kilometer, it would avoid only Seyler Reservoir and would add a designated riparian area northwest of Belmont.

Biology: The desert tortoise is the only threatened or endangered species found along the Carlin Corridor. The southern 50 kilometers (30 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (DIRS 104593-CRWMS M&O 1999, p. 3-25). Three other species (ferruginous hawk [*Buteo regalis*], San Antonio pocket gopher [*Thomomys umbrinus curtatus*], and Nevada sand dune beardtongue [*Penstemom arenarius*]) classified as sensitive by the Bureau of Land Management or as protected by the State of Nevada have been found along the Carlin Corridor. Additionally, the rail corridor crosses approximately 7 areas designated as game habitat by the Bureau of Land Management (DIRS 104593-CRWMS M&O

1999, p. 3-25). None of these species or game habitats are restricted to floodplains or areas that may have wetlands.

Archaeology: There are 110 archaeological sites that have been recorded along the Carlin Corridor (DIRS 104997-CRWMS M&O 1999, Table 3, p. 59).

L.3.2.3 Caliente-Chalk Mountain Corridor

Flooding: The Caliente-Chalk Mountain Corridor crosses 281 washes en route to the Yucca Mountain site (DIRS 154961-CRWMS M&O 1998, all). Approximately five washes along this route are large enough that bridges would be required to cross them. Based on the Federal Emergency Management Agency flood map data summarized in Table L-4, this corridor would cross only three different 100-year flood zones or flood zone groups before entering the Nellis Air Force Range. Two of the four alternative segments applicable to this corridor (see Table L-5) would change the number of flood zones crossed, but changes would be up or down by only one. The low number of flood zones identified for the Caliente-Chalk Mountain Corridor should be qualified by the fact that a great majority of this corridor, as noted in Table L-4, is not covered by flood maps. This is due to limited coverage in Lincoln County and no coverage inside the Nellis Air Force Range and the Nevada Test Site. Additional floodplain definition has not occurred.

Wetlands: At least one spring or group of springs and two streams that may have associated wetlands occur within 0.4 kilometer (0.25 mile) of the Caliente-Chalk Mountain Corridor. However, no field searches or formal delineations of wetlands have been conducted along this route. An unnamed spring is near the corridor at the north end of the North Pahroc Range. The corridor crosses Meadow Valley Wash south of Panaca. The corridor crosses the White River between U.S. 93 and Sand Spring Valley and parallels the river for approximately 10 kilometers (6 miles). That portion of the White River normally is dry.

Biology: The desert tortoise is the only threatened or endangered species found along the Caliente-Chalk Mountain Corridor. The southern 40 kilometers (25 miles) of this corridor is within desert tortoise habitat. This area is not designated as critical habitat and the abundance of tortoises in the area is low (DIRS 104593-CRWMS M&O 1999, p. 3-27). Southwestern willow flycatchers, an endangered species, have been observed in dense stands of riparian vegetation in Lincoln County, but there is no suitable habitat for this species in the corridor (DIRS 152511-Brocoum 2000, pp. A-9 to A-13). Four species (Meadow Valley Wash speckled dace, Meadow Valley Wash desert sucker, Ripley's springparsley [*Cymopterus ripleyi* var. *saniculoides*], and largeflower suncup [*Camissonia megalantha*]) classified as sensitive by the Bureau of Land Management or protected by Nevada have been found in the Caliente-Chalk Mountain Corridor. This rail corridor crosses approximately six areas designated as game habitat and one area of waterfowl habitat (DIRS 104593-CRWMS M&O 1999, p. 3-27). Two of these sensitive species, the speckled dace and desert sucker, are restricted to the floodplain of the Meadow Valley Wash. The designated waterfowl habitat also is generally restricted to the floodplain of Meadow Valley Wash and adjacent wetlands.

Archaeology: There are 100 archaeological sites that have been recorded along the Caliente-Chalk Mountain route Corridor (DIRS 104997-CRWMS M&O 1999, Table 3, p. 59).

L.3.2.4 Jean Corridor

Flooding: The Jean Corridor, Wilson Pass Option, crosses 89 washes en route to the Yucca Mountain site (DIRS 154961-CRWMS M&O 1998, all). Approximately five washes along this route are large enough that bridges would be required to cross them. This corridor would cross seven different 100-year flood zones or flood zone groups (see Table L-4) before entering the Nevada Test Site. Use of the

Stateline Pass Option to this corridor (see Table L-5) would increase the number of flood zones crossed by one. Use of the Pahrump Valley Alternate would result in no change. Federal Emergency Management Agency flood map coverage of this corridor is the highest in terms of percentage of any of the rail corridors. Additional floodplain definition has not occurred.

Wetlands: No springs, perennial streams, or riparian areas that may have associated wetlands have been identified within 0.4 kilometer (0.25 mile) of the Jean Corridor or its variations (DIRS 104593-CRWMS M&O 1999, p. 3-29). However, no field searches or formal delineations of wetlands have been conducted along this route.

Biology: The desert tortoise is the only threatened or endangered species found along the Jean Corridor. This entire corridor, including its variations, is within desert tortoise habitat, but does not cross any areas designated as critical habitat. The abundance of desert tortoises is low along most of the rail corridor, although there is a higher abundance along some portions in Ivanpah, Goodsprings, Mesquite, and Pahrump valleys (DIRS 104593-CRWMS M&O 1999, p. 3-28). One species, the pinto beardtongue (*Penstemon bicolor* spp.) that is classified as sensitive by the Bureau of Land Management has been found within the corridor. This rail corridor crosses approximately 10 areas designated as game habitat by the Bureau of Land Management (DIRS 104593-CRWMS M&O 1999, p. 3-28). None of these species or game habitats are restricted to floodplains or areas that may have wetlands.

Archaeology: Six archaeological sites have been recorded along the Jean Corridor (DIRS 104997-CRWMS M&O 1999, Table 3, p. 59).

L.3.2.5 Valley Modified Corridor

Flooding: The Valley Modified Corridor crosses 95 washes en route to the Yucca Mountain site (DIRS 154961-CRWMS M&O 1999, pp. 3 to 4). Approximately three washes along this route are large enough that bridges would be required to cross them. Based on the Federal Emergency Management Agency flood map data summarized in Table L-4, this corridor would cross only two different 100-year flood zones or flood zone groups before entering the Nevada Test Site. Of the three variations to this corridor (see Table L-5), the Indian Hills Alternate (number 21 in Table L-5) would decrease the number of flood zones to one; the other two variations would have no change. Flood map coverage of the Valley Modified Corridor is relatively good at about 75 percent. Additional floodplain definition has not occurred.

Wetlands: No springs, perennial streams, or riparian areas that may have associated wetlands have been identified within 0.4 kilometer (0.25 mile) of the Valley Modified Corridor or its variations (DIRS 104593-CRWMS M&O 1999, pp. 3-29 to 3-30). However, no field searches or formal delineations have been conducted along this route.

Biology: The desert tortoise is the only threatened or endangered species found along the Valley Modified Corridor. This entire corridor, including its variations, is within desert tortoise habitat, but does not cross any areas designated as critical habitat. The abundance of desert tortoises is low along this rail corridor (DIRS 104593-CRWMS M&O 1999, p. 3-29). Two plant species (Parish's scorpionweed [*Phacelia parishii*] and Ripley's springparsley) classified as sensitive by the Bureau of Land Management have been found in the rail corridor. None of these species are restricted to floodplains or areas that may have wetlands. The Valley Modified Corridor does not cross any Bureau of Land Management-designated game habitat (DIRS 104593-CRWMS M&O 1999, p. 3-29).

Archaeology: Nineteen archaeological sites have been recorded along the Valley Modified Corridor (DIRS 104997-CRWMS M&O 1999, Table 3, p. 59).

L.3.2.6 Caliente Intermodal Transfer Station

Flooding: The two proposed sites for the Caliente intermodal transfer station are located in the Meadow Valley Wash south of Caliente. Both areas are outside the inundation boundary of the 100-year floodplain, but within the boundary of the 500-year floodplain.

Wetlands: Part of the proposed station location is moist during at least some portions of the year. There are no springs on the site; there are springs adjacent to the site and some areas within the site have soils and plant species indicative of wetlands. Many of these moist areas are believed to be the result of irrigation with treated effluent from the wastewater treatment facility within the site, but some might qualify as wetlands or other waters of the United States if they are the result of outflow from nearby springs or the adjacent Meadow Valley Wash. The adjacent perennial stream and riparian habitat along Meadow Valley Wash also might be classified as wetlands, although no formal delineation of wetlands has been conducted for this proposed activity (DIRS 104593-CRWMS M&O 1999, p. 3-35).

Biology: No game habitat, threatened or endangered species, or species classified as sensitive by the Bureau of Land Management or protected by Nevada occur within the proposed station location (DIRS 104593-CRWMS M&O 1999, p. 3-35). Although the Federally endangered Southwestern willow flycatcher has been detected in Meadow Valley Wash, there is no habitat for this species on this site (DIRS 152511-Brocoum 2000, pp. A-9 to A-13).

Archaeology: Four archaeological sites have been recorded at the Caliente intermodal transfer station site (DIRS 104997-CRWMS M&O 1999, Table 2, p. 32).

L.3.2.7 Apex/Dry Lake Intermodal Transfer Station

Flooding: The three proposed sites for the Apex/Dry Lake intermodal transfer station are outside the 100-year and 500-year floodplains.

Wetlands: There are no springs or riparian areas within the proposed station location (DIRS 104593-CRWMS M&O 1999, p. 3-36).

Biology: The only resident threatened or endangered species at this site is the desert tortoise. The abundance of desert tortoises in Dry Lake Valley generally is low, although some areas there have a higher abundance. One plant species, Geyer's milkvetch (*Astragalus geyeri triquetrus*), classified as sensitive by the Bureau of Land Management has been found in the proposed location. Neither of these species are restricted to floodplains or wetlands. No game habitat has been designated there (DIRS 104593-CRWMS M&O 1999, p. 3-36).

Archaeology: Two archaeological sites have been recorded at the Apex/Dry Lake intermodal transfer station site (DIRS 104997-CRWMS M&O 1999, Table 2, p. 32).

L.3.2.8 Sloan/Jean Intermodal Transfer Station

Flooding: The southernmost proposed site for the Sloan/Jean intermodal transfer station is located in the same general area as a 100-year flood inundation zone. The middle site is not in an inundation zone and is outside the 500-year floodplain. The northernmost proposed site is in an area with no printed Federal Emergency Management Agency map and it is outside the 500-year floodplain.

Wetlands: There are no springs or riparian areas within the proposed station location (DIRS 104593-CRWMS M&O 1999, p. 3-36).

Biology: The only resident threatened or endangered species at this site is the desert tortoise. The abundance of desert tortoises in Ivanpah Valley generally is moderate to high, relative to other areas within the range of this species in Nevada. One plant species, pinto beardtongue, classified as sensitive by the Bureau of Land Management has been found in the proposed location. Neither of these species are restricted to floodplains or wetlands. No game habitat has been designated there (DIRS 104593-CRWMS M&O 1999, pp. 3-36 to 3-37).

Archaeology: Seven archaeological sites have been recorded at the Sloan/Jean intermodal transfer station site (DIRS 104997-CRWMS M&O 1999, Table 2, p. 32).

L.4 Floodplain/Wetlands Effects

According to 10 CFR 1022.12(a)(2), a floodplain assessment is required to discuss the positive and negative, direct and indirect, and long- and short-term effects of the proposed action on the floodplain and/or wetlands. In addition, the effects on lives and property, and on natural and beneficial values of floodplains must be evaluated. For actions taken in wetlands, the assessment should evaluate the effects of the proposed action on the survival, quality, and natural and beneficial values of the wetlands. If DOE finds no practicable alternative to locating activities in floodplains or wetlands, DOE will design or modify its actions to minimize potential harm to or in the floodplains and wetlands. The floodplains that are assessed herein are those areas of normally dry washes that are temporarily and infrequently inundated from runoff during 100-year or 500-year floods.

L.4.1 FLOODPLAIN/WETLANDS EFFECTS NEAR YUCCA MOUNTAIN

DOE has not determined if rail casks will be transported in Nevada by heavy-haul trucks on existing highways or whether to construct a branch rail line to bring the spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Near Yucca Mountain, however, it is possible that each of the four washes could be affected if a rail line and a road were to access the Yucca Mountain site from different directions. Because of this uncertainty, this assessment examines the configurations that would cause the most disturbances to the four washes and their floodplains, as follows:

- Potential construction of a heavy-haul-capable road west of Fortymile Wash that crosses Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash. Cut, fill, and drainage culverts could be used to cross Busted Butte and Drill Hole washes. A bridge could be constructed over Midway Valley Wash. Heavy-haul trucks carrying spent nuclear fuel and high-level radioactive waste could travel along this road to the repository.

- Potential construction of a raised rail line through Fortymile Wash with appropriately-sized drainage culverts. The rail line could join the route for heavy-haul trucks north of Drill Hole Wash and cross Midway Valley Wash on a separate rail-bridge before entering the repository. Trains carrying spent nuclear fuel and high-level radioactive waste could travel along the rail line to the repository.

- Potential upgrading of the existing road that crosses Fortymile Wash with appropriately-sized drainage culverts. The road could be used by legal-weight trucks to transport spent nuclear fuel and high-level radioactive waste to the repository, as well as transporting various types of hazardous and non-hazardous materials to and from the repository.

Construction in the washes would reduce the area through which floodwaters naturally flow. During large floods, bodies of water could develop on the upstream side of each of the crossings and slowly drain through culverts. Such floods, however, would not increase the risk of future flood damage, increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains because there are no human activities or facilities upstream or downstream that could be affected. A sufficiently large flood in Fortymile Wash could create a temporary large lake up-stream of the raised rail line and the legal-weight road. The water would slowly drain through culverts. If the flood occurred quickly and was sufficiently large, water would flow over the rail line and roads and continue downstream. Some damage to the rail line and the roads would be expected, but neither structure would increase the risk of future flood damage, increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains because there are no human activities or facilities downstream that could be affected.

During and after each flood, a large amount of sediment would accumulate on the up-stream side of each crossing. Periodically, this material would have to be removed so that future floods would have sufficient space to accumulate, rather than overflow the structures during successively smaller floods. This material would, when deemed necessary, be removed by truck and disposed of appropriately. Under natural conditions this sediment would have continued downstream and been deposited as the floodwaters receded. Compared to the total amount of sediment that is moved by the flood water along the entire length of the washes, the amount trapped behind the crossings would be small.

During a 100-year or 500-year flood, there would be no preferred channels; all channels across the entire width of each wash would be filled with water (Figure L-1). Therefore, the manmade crossings would not cause preferential flow in a particular channel or alter the velocity or direction of flow on the floodplains.

Potential construction of a route for heavy-haul trucks or rail line would require the removal of desert vegetation in the washes and the disturbance of soil and alluvium. These actions could adversely impact wildlife habitat and individuals, especially the desert tortoise, which is designated as threatened by the Fish and Wildlife Service. Prior to any construction, a biological survey would be conducted to locate and remove tortoises that are in the path of construction and other mitigation measures would be conducted as identified by the Fish and Wildlife Service during consultations under the Endangered Species Act for this action.

Construction in the floodplains could also affect unidentified cultural resources that may be present. Prior to any construction, archaeologists would survey the area following the procedure in DOE's Programmatic Agreement with the Advisory Council on Historic Preservation (DIRS 104558-DOE 1988, p. 5). DOE would avoid such sites if possible or, if it was not possible, would conduct a data recovery program of the sites in accordance with applicable regulatory requirements and input from official tribal contact representatives and document the findings. The artifacts from and knowledge about the site would be preserved. Improved access to the area could lead to indirect impacts, which could include unauthorized excavation or collection of artifacts. Workers would have required training on the protection of these resources from excavation or collection.

Potential indirect impacts on flora and fauna include increased emissions of fugitive dust, elevated noise levels, and increased human activities. Emissions of fugitive dust would be short-term and would not be expected to significantly affect vegetation or wildlife. Likewise, no significant long-term impacts to wildlife are expected from the temporary increase in noise during construction. Wildlife displaced during construction would probably return after construction was completed.

There are no perennial sources of surface water at or downstream from the Yucca Mountain site that would be affected by the use of a route for heavy-haul trucks or the construction of a rail line. Two small well ponds with some riparian vegetation occur in Fortymile Wash downstream of the point where Drill Hole Wash enters Fortymile Wash. During a 100- or 500-year flood, both riparian areas would likely be damaged or destroyed by floodwaters regardless of the existence of the crossings.

Neither the quality nor the quantity of groundwater that normally recharges through Fortymile Wash would be substantially affected due to the crossings. Water infiltration could increase somewhat after large floods as standing water slowly enters the ground behind the crossings. The total volume of these water bodies would be a few acre-feet at most, and much of the water would gradually drain through culverts or evaporate before reaching the groundwater table at 274 meters (900 feet) below the surface.

The use of petroleum, oil, lubricants, and other hazardous materials during construction would be strictly controlled and spills would be promptly cleaned up and, if needed, the soil and alluvium would be remediated. The small amount of these materials that might enter the ground would not affect the groundwater, which is 274 meters (900 feet) below the surface.

The nearest population center is about 22 kilometers (14 miles) to the south, along U.S. 95 within the community of Amargosa Valley a few miles east of Fortymile Wash. If floodwaters from a 100- or 500-year flood reached this far downstream, there would be no measurable increase in flood velocity or sediment load attributable to the use of a route for heavy-haul trucks or construction of a rail line compared to natural conditions. Hence, disturbances to the floodplains of Fortymile Wash, Busted Butte Wash, Drill Hole Wash, or Midway Valley Wash would have no adverse impacts on lives and property downstream. Moreover, impacts to these floodplains would be insignificant in both the short- and long-term compared to the erosion and deposition that occur naturally and erratically in these desert washes and floodplains.

During operation of the repository it would be extremely unlikely that a truck carrying spent nuclear fuel and high-level radioactive waste would fall into Busted Butte, Drill Hole, or Midway Valley washes or that a train would derail in Fortymile Wash. However, even if this occurred, the shipping casks, which are designed to prevent the release of radioactive materials during an accident, would remain intact. The casks would then be recovered and transported to the repository. No adverse impacts to surface water or groundwater quality from such accidents would occur.

Hazardous materials needed during construction and operation of the repository would be transported along the legal-weight access road. If these materials were released during an accident, they would be cleaned-up quickly and the affected soil and alluvium would be remediated. No adverse impacts to groundwater quality from such accidents would occur because cleanup could be completed before contaminants reached the groundwater [the groundwater table is 274 meters (900 feet) below the surface].

There are no positive or beneficial impacts to the floodplains of Busted Butte, Drill Hole, Midway Valley, or Fortymile washes that have been identified from the proposed action.

L.4.2 FLOODPLAIN/WETLANDS EFFECTS ELSEWHERE IN NEVADA

L.4.2.1 Effects along Rail Corridors

The candidate rail corridors, including their variations, would cross many small, and some large, washes. In general, the impacts caused by rail construction in any of these washes and their floodplains would be similar in magnitude to those described for Fortymile, Busted Butte, Drill Hole, and Midway Valley washes. Regardless of the corridor selected, standard mitigation practices would be used to minimize the impacts to floodplains. Most washes and their floodplains along the five candidate rail corridors are in remote areas. Impacts to these floodplains from rail construction and operation would be insignificant in both the short- and long-term compared to erosion and deposition that occurs naturally and erratically in these desert washes and floodplains.

Based on current information, springs and riparian areas that may have associated wetlands occur within three of the rail corridors (Caliente, Carlin, and Caliente-Chalk Mountain.) If the rail mode of spent nuclear fuel and high-level radioactive waste transport in Nevada is selected by DOE, wetlands delineations along the selected corridor would be conducted and the effects would be described in a more detailed floodplain/wetlands assessment for public review.

L.4.2.2 Effects at Intermodal Transfer Stations

Neither the Dry Lake intermodal transfer station nor the northern two sites being considered for the Sloan/Jean intermodal transfer station would have any impacts on floodplains because these station locations are not in a floodplain. The Caliente intermodal transfer station, however, is located in Meadow Valley Wash, separated by the Union Pacific Railroad and the southernmost of the Sloan/Jean sites is in the area of a wash or drainage channel between Interstate 15 on the west and the Union Pacific Railroad on the east. If one of these sites was selected, DOE would conduct a more detailed floodplain/wetlands assessment for public review to address the floodplain/wetlands effects at the Caliente or Sloan/Jean intermodal transfer station location. The more detailed floodplain/wetlands assessment would also include potential upgrades to existing roads for heavy-haul use.

L.5 Mitigation Measures

According to 10 CFR 1022.12(a) (3), agencies must address measures to mitigate the adverse impacts of actions in a floodplain or wetlands, including but not limited to minimum grading requirements, runoff controls, design and construction constraints, and protection of ecologically-sensitive areas. Whenever possible, DOE would avoid disturbing wetlands and floodplains and would minimize impacts to the extent practicable, if avoidance was not possible. This section discusses the floodplain mitigation measures that would be considered in the vicinity of Yucca Mountain and elsewhere in Nevada and, where necessary and feasible, implemented during construction and maintenance in the washes.

Adverse impacts to the affected floodplains would be small. Even during 100- and 500-year floods, it is unlikely that differences in the rate and distribution of erosion and sedimentation caused by the use of a route for heavy-haul trucks or construction of a branch rail line near Yucca Mountain would be measurably different compared to existing conditions. Similarly, upgrades to access roads and placement of excavated rock stockpiles within the site area would have little affect on erosion and sedimentation from flooding events. Nevertheless, DOE would follow their reclamation guidelines (DIRS 102188-YMP 1995, pp. 2-1 to 2-14) for site clearance, topsoil salvage, erosion and runoff control, recontouring, revegetation, siting of roads, construction practices, and site maintenance. Disturbance of surface areas and vegetation would be minimized, and natural contours would be maintained to the maximum extent feasible. Slopes would be stabilized to minimize erosion. Unnecessary off-road vehicle travel would be avoided. Storage of hazardous materials during construction would be outside the floodplains.

Before any potential construction could begin, DOE would require pre-construction surveys to make sure that the work would not impact important biological or archaeological resources. In addition, the site's reclamation potential would be determined during these surveys. In the event that construction could threaten important biological or archaeological resources, and modification or relocation of the roads and rail line is not reasonable, mitigation measures would be developed. Mitigation measures developed during the pre-construction surveys would be incorporated into the design of the work. These measures could include relocation of sensitive species, avoidance of archaeological sites, or data recovery if avoidance is not feasible.

If hazardous materials are spilled during construction of the crossings or during transport to the repository, the spill would be quickly cleaned-up and the soil and alluvium would be remediated. Hazardous materials would be stored away from all floodplains to decrease the probability of an inadvertent spill in these areas.

L.6 Alternatives

According to 1022.12(a)(3), DOE must consider alternatives to the proposed action. Alternative ways to access the Yucca Mountain site are considered in the following paragraphs, along with the No-Action Alternative.

L.6.1 ALTERNATIVES NEAR YUCCA MOUNTAIN

To operate a potential repository at Yucca Mountain, heavy-haul-capable and other roads and a branch rail line to the facility would be considered so the spent nuclear fuel and high-level radioactive waste could be unloaded and emplaced underground. It is unreasonable to consider a railroad or heavy-haul-capable and other roads that access the repository directly from the west over Yucca Mountain because of engineering constraints, environmental damage, and cost associated with construction in such rugged terrain. Because of these concerns, this alternative was eliminated from detailed consideration.

Access to Yucca Mountain from the east side requires that Fortymile Wash be crossed. Alternative sites for these crossings were considered, but the impacts at any alternative site would be virtually identical to each other.

L.6.2 ALTERNATIVE RAIL CORRIDORS AND ALTERNATIVE SITES FOR AN INTERMODAL TRANSFER STATION

Five candidate rail corridors were identified by DOE through a winnowing process that considered a host of environmental constraints (see Chapter 2, Section 2.3.3). Other possible rail corridors in Nevada were examined but rejected because of such things as land use, private land, and engineering constraints. Identification of the three intermodal transfer station locations was limited to reasonable sites next to an existing rail line in Nevada. Other sites were considered by DOE, but rejected because of ownership and environmental concerns.

L.6.3 NO-ACTION ALTERNATIVE

Selection of the No-Action Alternative would avoid impacts to floodplains and wetlands. If Yucca Mountain was selected as a site to construct a repository, transport of spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site would be required. In that case there would be no other practicable alternative to taking action in floodplains and wetlands because there would be no way to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site during repository operation without passing through some wetlands areas and floodplains.

L.7 Floodplain Statement of Findings

DOE prepared this Floodplain Statement of Findings based on the information in the above floodplain/wetlands assessment. The assessment evaluates potential effects to the floodplains near Yucca Mountain (Fortymile Wash, Busted Butte Wash, Drill Hole Wash, and Midway Valley Wash) and to floodplains and wetlands elsewhere in Nevada from construction of a branch rail line or an intermodal transfer station and associated upgrades to existing highways for heavy-haul trucks. The assessment describes the proposed repository project and the existing environment near Yucca Mountain and elsewhere in Nevada along each of five candidate rail corridors and at three potential intermodal transfer station locations and five potential routes for heavy-haul trucks (see Figures L-1, L-2, and L-3 for location maps).

No repository surface facilities would be located in either the 100-year or the 500-year floodplains of Fortymile Wash, Busted Butte Wash, Drill Wash, or Midway Wash. Access roads within the repository site would cross through upper portions of Drill Hole Wash and its tributaries. Stockpiles of rock excavated from the subsurface could also affect small drainage channels. Under the Proposed Action in this EIS, spent nuclear fuel and high-level radioactive waste would be shipped to the repository over approximately 24 years. Because there is no rail access to the Yucca Mountain site, DOE would need heavy-haul-capable and legal-weight roads or a potential rail line so that spent nuclear fuel and high-level radioactive waste could be delivered to Yucca Mountain. If the Yucca Mountain site was approved for development as a repository, there is no practicable alternative to locating roads and a potential rail line in a floodplain near Yucca Mountain.

Depending on the particular rail corridor or heavy-haul route selected, route construction and operations would affect floodplains in the vicinity of the Yucca Mountain site. These effects would occur from the installation of drainage culverts to cross some of the washes (e.g., Busted Butte and Drill Hole Washes), upgrading the existing road that crosses Fortymile Wash, or construction of a bridge for rail or heavy-haul traffic over Midway Valley Wash. Activities in the washes could also reduce the area through which floodwaters naturally flow. However, none of these impacts would be expected to increase the risk of future flood damage, or increase the impact of floods on human health and safety, or harm the natural and beneficial values of the floodplains because there are no human activities or facilities upstream or downstream that could be affected. There are no delineated wetlands at or near Yucca Mountain.

Similarly, elsewhere in Nevada, there would be no practicable alternative to taking action in floodplains and wetlands because there would be no means to transport spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site without passing through some wetlands areas and floodplains.

In addition to the Proposed Action, the EIS analyzes a No-Action Alternative. Under the No-Action Alternative, no impacts to floodplains and wetlands would occur. DOE considered other alternative routes or access points to Yucca Mountain in addition to the five candidate rail corridors in Nevada and the three potential intermodal transfer station locations and five associated heavy-haul truck routes that are evaluated in the EIS. However, these other alternative routes or access points were eliminated from further detailed review on the basis of engineering constraints, environmental damage, and construction costs, and because they did not provide as direct a route to the repository as the candidate corridors and routes.

If Yucca Mountain was approved for development of a repository, DOE would choose either a rail corridor or an intermodal transfer station location and associated route for heavy-haul trucks to transport spent nuclear fuel and high-level radioactive waste to the repository. DOE would conduct a more detailed floodplains evaluation and wetlands delineation along the selected route. The effects and potential mitigation measures to be implemented for the selected route would be described in more detail in a floodplains and wetlands assessment to be issued for public review. DOE would minimize potential harm to or within a floodplain or wetland, such as by avoiding these resources in any selection of an alignment within a rail corridor.

Further, during any construction and operations at the Yucca Mountain site or elsewhere in Nevada along candidate rail corridors or at candidate sites for an intermodal transfer station, DOE would avoid disturbing wetlands, sensitive species, and floodplains wherever possible. If avoidance would not be practicable, standard mitigation practices would be used to minimize the potential impacts to floodplains and wetlands in the proposed project area and elsewhere in Nevada. Procedures would include preconstruction and biological surveys to identify and relocate sensitive species; avoiding archaeological sites (or data recovery where avoidance would not be feasible); modifying designs and implementing good engineering practices such as minimizing size of disturbance areas, topsoil salvage, preserving natural contours, surface erosion or runoff control; reclaiming and revegetating disturbed areas; and following established guidelines for hazardous materials storage and accidental spill response.

DOE's Proposed Action in floodplains would be conducted in accordance with all applicable requirements, including any applicable State or local floodplain protection standards.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Site Characterization Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

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Appendix M

Supplemental Transportation Information

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APPENDIX M. SUPPLEMENTAL TRANSPORTATION INFORMATION

Radioactive materials are in common use in the United States for a wide range of purposes, including medical applications, precision instrumentation, and home products such as smoke detectors. Shipments of these materials occur throughout the country every day. A variety of regulations govern these shipments to ensure safety. Of the estimated 3 million annual radioactive material shipments, most involve low-level materials. Of the more than 2,700 shipments of commercial spent nuclear fuel completed over the past 30 years, none has resulted in an identified injury caused by the release of radioactive materials. While a repository would increase the total number of all radioactive materials shipments, spent nuclear fuel and high-level radioactive waste shipments would be a small fraction of the total. Furthermore, the number of shipments of radioactive materials is small in comparison to the 300 million annual shipments of hazardous materials.

The U.S. Department of Energy (DOE or the Department) developed this appendix to provide general background information on transportation-related topics not addressed in detail in Chapter 6 or Appendix J of this environmental impact statement (EIS). Although this information is not essential for analyzing potential impacts associated with transportation, DOE, in response to public comments on the Draft EIS, is including it to help the reader understand the regulatory framework and safety provisions associated with transporting spent nuclear fuel and high-level radioactive waste. This appendix describes the types of radioactive wastes commonly shipped by DOE and others and the relevant transportation requirements for each. In addition, it highlights the regulations developed by the U.S. Department of Transportation and the Nuclear Regulatory Commission to regulate virtually every aspect of the transportation of radioactive materials, including spent nuclear fuel and high-level radioactive waste. Further, it describes the transportation operations and requirements that would apply specifically to a Yucca Mountain Repository if it was recommended and approved. In that context, this appendix also discusses the safety and testing of transportation casks, emergency response in case of a transportation accident, physical protection of radioactive materials, and liability.

M.1 Spent Nuclear Fuel and Radioactive Wastes and General Transportation Requirements

Because the hazard levels of spent nuclear fuel, high-level radioactive waste, and other radioactive wastes vary, the transportation requirements for each also vary. This section describes spent nuclear fuel and other types of radioactive waste, and the general transportation requirements pertaining to each.

M.1.1 SPENT NUCLEAR FUEL

Spent nuclear fuel results from the production of electricity at nuclear powerplants or from the operation of other nuclear reactors, such as research reactors. Spent nuclear fuel is reactor fuel that has been withdrawn from a reactor following irradiation, the component elements of which have not been separated by reprocessing. It includes the following forms:

- Intact nondefective fuel assemblies
- Failed fuel assemblies in canisters
- Fuel assemblies in canisters
- Consolidated fuel rods in canisters
- Nonfuel assembly hardware inserted in pressurized-water reactor fuel assemblies
- Fuel channels attached to boiling-water reactor fuel assemblies
- Nonfuel assembly hardware and structural parts of assemblies resulting from consolidation in canisters

Any of the materials fitting this definition would be transported to a repository in shipping casks certified by the Nuclear Regulatory Commission under the regulations discussed in Section M.2.

M.1.2 HIGH-LEVEL RADIOACTIVE WASTE

High-level radioactive waste is a byproduct of the reprocessing of spent nuclear fuel. During reprocessing, spent nuclear fuel is separated into material to be reused, such as uranium and plutonium, and waste material for disposal. High-level waste includes liquid waste produced directly during reprocessing and solid material derived from such liquid waste that contains fission products in sufficient concentrations. Other highly radioactive wastes determined by the Nuclear Regulatory Commission to require permanent isolation can also be high-level waste. To date, there have been no such determinations. High-level waste would be transported in solid form to a repository in the same manner as spent nuclear fuel in accordance with the regulations discussed in Section M.2.

M.1.3 LOW-LEVEL RADIOACTIVE WASTE

Low-level radioactive waste is basically any radioactive waste that is not high-level radioactive waste, spent nuclear fuel, transuranic waste, or byproduct materials, such as uranium mill tailings. It results from research, medical, and industrial processes that use radioactive materials. Commercial powerplant operations and defense-related activities, including weapons disassembly and cleanup of production sites, also produce low-level waste. In addition, repository operations, such as the decontamination of transportation casks and the decontamination and decommissioning of facilities after completion of operations, could generate low-level radioactive waste.

Low-level radioactive waste usually contains small amounts of short-lived radioactive material dispersed through large quantities of other material. It poses little transportation risk. Typically, such wastes consist of used protective clothing, rags, tools and equipment, used resins and residues, dirt, concrete, construction debris, and scrap metal. This waste is usually packaged in sturdy wooden or steel crates and steel drums for shipment. Because of its level of radioactivity, some types of low-level waste are transported in shielded Type B packages, which are certified by the Nuclear Regulatory Commission (see Section M.2.1). The Commission requires that all low-level waste be in solid form (free of liquids) before shipment to a disposal facility. The U.S. Department of Transportation requires carriers of low-level radioactive waste to use routes that minimize radiological risk [49 CFR 397.101(a)]. There are several sites across the United States for low-level radioactive waste disposal. Such waste would not be disposed of at Yucca Mountain.

Mixed waste contains both hazardous chemical components and radioactive components and is subject to the requirements of the Atomic Energy Act, as amended (42 U.S.C. 2011 *et seq.*) and the Resource Conservation and Recovery Act, as amended (42 U.S.C. 6901 *et seq.*). Most mixed waste is low-level; however, some transuranic waste is classified as mixed waste.

M.1.4 TRANSURANIC WASTE

Transuranic waste contains elements heavier than uranium, thus the name *trans*- (or beyond) -*uranic*. It results from both defense and nondefense production activities and includes contaminated protective clothing, tools, glassware, and equipment. Transuranic waste from defense production activities is disposed of at the Waste Isolation Pilot Plant in New Mexico. The transuranic waste category was established to separate long-lived, alpha-emitting radionuclides from the low-level radioactive waste stream. Thus, transuranic waste includes wastes contaminated with alpha-emitting transuranic radionuclides with half-lives greater than 20 years and concentrations greater than 100 nanocuries per gram. Waste containing less than 100 nanocuries per gram of transuranic contamination is classified as low-level waste. The gross radiation levels of transuranic waste are much less than those of high-level radioactive wastes, which emit significant amounts of beta and gamma radiation.

There are two types of transuranic waste, based on the amount of radioactivity. These wastes are typically shipped in 208-liter (55-gallon) drums or metal boxes transported in Type B packages. Almost all transuranic waste is *contact-handled*, meaning that it can be handled safely without shielding other than the drum or box. A small portion of transuranic waste is *remote-handled*, which must be transported in shielded casks.

DOE transports transuranic waste to the Waste Isolation Pilot Plant in New Mexico in accordance with U.S. Department of Transportation and Nuclear Regulatory Commission requirements. This transportation follows protocols agreed to in *Memorandum of Agreement for Regional Protocol for the Safe Transport of Transuranic Waste to the Waste Isolation Pilot Plant* (DIRS 155717-O'Leary 1995, all). Although not every shipment is classified as a Highway Route-Controlled Quantity of Radioactive Material, DOE has stated that, as a matter of policy, all shipments to the Waste Isolation Pilot Plant will follow U.S. Department of Transportation routing requirements for Highway Route-Controlled Quantities (see Section M.2.). A Highway Route-Controlled Quantity of Radioactive Material is a quantity in a single shipment that exceeds the amount of radioactivity specified in 49 CFR 173.425 and 10 CFR 71, Appendix A, Table A2. Highway and rail shipments of spent nuclear fuel and high-level radioactive waste to a Yucca Mountain Repository, if approved, would meet the definition of Highway Route-Controlled Quantities of Radioactive Material.

M.2 Transportation Regulations

DOE shipments of spent nuclear fuel and high-level radioactive waste from reactors and DOE sites around the country to a repository at Yucca Mountain would comply with applicable Federal, Native American, state, and local government regulations. The U.S. Department of Transportation and the Nuclear Regulatory Commission share primary responsibility for regulating the safe transport of radioactive materials in the United States. These agencies have implemented regulations to govern the transportation of radioactive materials consistent with international transport safety standards.

The Hazardous Materials Transportation Act, as amended (49 U.S.C. 1801), directs the U.S. Department of Transportation to develop transportation safety standards for hazardous materials, including radioactive materials. Title 49 of the Code of Federal Regulations contains the standards and requirements for packaging, transporting, and handling radioactive materials for all modes of transportation.

The Nuclear Regulatory Commission regulates the transportation-related operations of its licensees, including commercial shippers of radioactive materials. It sets design and performance standards for packages that carry materials with higher levels of radioactivity (10 CFR). The Nuclear Waste Policy Act, as amended (NWPA; 42 U.S.C. 10101 *et seq.*), all shipments to Yucca Mountain would be made in Commission-certified packages and in accordance with Commission regulations on the advance notification of state and local governments (Section 180).

M.2.1 PACKAGING

Packages for radioactive materials that meet the standards required by U.S. Department of Transportation and Nuclear Regulatory Commission regulations (see Section M.4.1) are the primary means to protect people and the environment during the transportation of radioactive materials. The type of package required depends on the radiological hazard of the material being transported. Packages are selected based on activity, type, and form of the material to be shipped. There are four basic types of packages for transporting radioactive materials:

- *Excepted* packages are for materials with extremely low levels of radioactivity, such as instrumentation and smoke detectors.
- *Industrial* packages are for materials that present a limited hazard to the public, including contaminated equipment and radioactive waste solidified in materials such as concrete.
- *Type A* packages are for materials with higher concentrations of radioactivity, such as radiopharmaceuticals and low-level radioactive waste.
- *Type B* packages are for materials with radioactivity levels higher than those allowed in Type A packaging. Type B packages range from small containers of sealed radioactive sources to heavily shielded steel casks that sometimes weigh as much as 136 metric tons (150 tons). Examples of materials transported in Type B packages include spent nuclear fuel, high-level radioactive waste, and other materials with high concentrations of radioisotopes, such as cobalt sources.

Another option, the strong tight package, is available for some domestic shipments of radioactive materials. It is authorized only for domestic shipments of certain materials with low levels of radioactivity in a vehicle hired exclusively for their transport.

All spent nuclear fuel and high-level radioactive waste shipments to Yucca Mountain would be in the most rugged casks, Type B. The Nuclear Regulatory Commission regulates and certifies the design, manufacture, testing, and use of Type B packages under regulations contained in 10 CFR Part 71.

All radioactive materials must be properly packaged so that external radiation levels do not exceed regulatory limits. The packaging protects package handlers, transporters, and the public against receiving dose rates in excess of recognized safe limits. Regulations in 10 CFR 71.47 and 49 CFR 173.441 prescribe the external radiation standards for all packages. For shipments to the proposed repository, the radiation limits would be 10 millirem per hour at any point 2 meters (6.6 feet) from the outer edge of the truck trailer or railcar.

M.2.2 MARKING, LABELING, AND PLACARDING

U.S. Department of Transportation regulations require that shippers meet specific hazard communication requirements in marking and labeling packages that contain radioactive materials and other hazardous materials. Markings provide the proper shipping name, an emergency response identification number, the shipper’s name and address, and other important information. Labels are placed on opposite sides of a package to identify the contents and radioactivity level.

The required label is determined by the type of material shipped and measured radiation levels of the package contents. Shippers of radioactive materials use one of three labels: Radioactive White I, Yellow II, or Yellow III. The use of a particular label is based on the radiation level at the surface of the package and the transport index, which is a dimensionless number placed on the label of a package to indicate the degree of control to be exercised by the carrier during shipment. It is determined in accordance with 49 CFR 172.403.

- A White I label is for a package with a surface radiation level less than or equal to 0.5 millirem per hour and a transport index of 0.

- A Yellow II label is for a package with a surface radiation level greater than 0.5 millirem but less than or equal to 50 millirem per hour and a transport index of not more than 1.
- A Yellow III label is for packages that require the greatest degree of control by a carrier. These packages include ones in which:
  - — The surface radiation level is greater than 50 millirem per hour but less than or equal to 200 millirem per hour, and the transport index is not greater than 10
  - — The surface radiation level is between 200 and 1,000 millirem per hour or the transport index is greater than 10 (shipment must be by an exclusive use vehicle)

Almost all spent nuclear fuel and high-level radioactive waste shipments to Yucca Mountain would have Yellow III labels. Some shipments of irradiated reactor fuel components and empty shipping casks could have Yellow II labels.

In addition, vehicles transporting certain shipments of radioactive materials must have hazard communication placards displayed clearly on all four sides. Some shipments containing a high level of radioactivity, including spent nuclear fuel and high-level radioactive waste are, by regulation, *Highway Route-Controlled Quantities of Radioactive Materials* and must have the required "Radioactive" placard placed on a square white background with a black border.

The shipper and carrier are responsible for using the correct markings, labels, and placards. Compliance with the requirements is enforced by the U.S. Department of Transportation and, for licensees, can also be enforced by the Nuclear Regulatory Commission. Markings, labels, and placards identify the hazardous contents to emergency responders in the event of an accident.

M.2.3 SHIPPING PAPERS

The shipper prepares shipping papers and gives them to the carrier. These documents contain additional details about the cargo and include a signed certification that the material is properly classified and in proper condition for transport. For transport to the proposed repository at Yucca Mountain, commercial sites would present DOE with loaded shipping casks and a certification that the casks have been properly loaded, assembled, and inspected. For its licensees, which includes all commercial nuclear power reactors, the Nuclear Regulatory Commission can enforce U.S. Department of Transportation regulations regarding preparation and offering of shipments to carriers for transport.

Shipping papers also contain emergency information, including contacts and telephone numbers. Carriers must keep shipping papers readily available during transport for inspection by appropriate officials, such as state inspectors.

M.2.4 ROUTING

Motor carriers of Highway Route-Controlled Quantities of Radioactive Materials, such as spent nuclear fuel and high-level radioactive waste, are required to use *preferred routes* that reduce time in transit [49 CFR 397.101(b)]. A preferred route is an Interstate System highway (including beltways and bypasses) or an alternative route selected by a state routing authority in accordance with 49 CFR 397.103 using U.S. Department of Transportation *Guidelines for Selecting Preferred Highway Routes for Highway Route-Controlled Quantity Shipments of Radioactive Materials* (57 *FR* 44131; September 24, 1992) or an equivalent routing analysis that adequately considers overall risk to the public. Prior to the shipment of spent nuclear fuel, the shipper or carrier, as appropriate, must select routes and prepare a written plan for the Nuclear Regulatory Commission listing origin and destination of the shipment, scheduled route, all planned stops, estimated time of departure and arrival, and emergency telephone numbers. The Nuclear Regulatory Commission reviews and approves such routes.

Except for requirements contained in 10 CFR 73.37, there are no Federal regulations pertaining to rail routes for shipment of spent nuclear fuel or high-level radioactive waste. The shipper and railroad companies (carriers) determine rail routes based on best available route and track conditions, schedule efficiency, and cost effectiveness. The routes must be submitted in advance to the Nuclear Regulatory Commission for approval.

The U.S. Coast Guard has participated in establishing barge routes used for shipments from reactor sites. The names of the ports to be used must be submitted in advance to the Nuclear Regulatory Commission.

The EIS analysis used computer programs to select routes that are representative of routes that could be used to ship spent nuclear fuel and high-level radioactive waste to a Yucca Mountain repository. The computer programs applied the regulatory requirements and industry practices discussed in this appendix. If the repository was approved, actual shipment route selections would be submitted to the Nuclear Regulatory Commission for approval 1 or more years before shipments began. Section M.3.2.1.2 discusses route selection in greater detail.

M.2.5 PRIOR NOTIFICATION

Nuclear Regulatory Commission regulations (10 CFR Part 73) provide for written notice to governors or their designees in advance of irradiated reactor fuel through their states. Federal regulations allow states to release certain advance information to local officials on a need-to-know basis. As required by Section 180 of the NWPA, all shipments to a repository would comply with Commission regulations on advanced notification to state and local governments.

The Nuclear Regulatory Commission is in the process of changing the requirements so that Native American governments would be notified under the Commission's notification rule (64 *FR* 71331, December 21, 1999). Notification of shipments to a repository would be in accordance with Commission regulations in effect at that time.

M.2.6 TRAINING

U.S. Department of Transportation regulations (49 CFR Part 391) require anyone involved in the preparation or transport of radioactive materials, including loading and unloading, packaging, documentation, or general transport safety, to have proper training. In accordance with 49 CFR 172, Subpart H, operators of vehicles transporting Highway Route-Controlled Quantities of Radioactive Materials receive special training that covers the properties and hazards of the radioactive materials being transported, regulations associated with hazardous material transport, and applicable emergency procedures. Operators must be recertified every 2 years.

M.2.7 OTHER REQUIREMENTS

Organizations representing different transport modes often establish mode-specific standards. For example, all North American shipments by rail that change carriers must meet Association of American Railroads interchange rules. Equipment in interchanges must meet Association of American Railroads *Field Manual of the A.A.R. Interchange Rules* (DIRS 102592-AAR 1998, all) requirements.

The Commercial Vehicle Safety Alliance has developed inspection procedures and out-of-service criteria for commercial highway vehicles transporting transuranics, and Highway Route-Controlled Quantities of

Radioactive Materials (see Section M.3.2.2.2). All highway shipments to a repository would be inspected under these procedures and would not leave the site until the vehicle was determined to be defect-free.

M.3 Transportation Plans and Requirements Specific to the Proposed Repository

This section describes current plans for implementing Section 137 of the NWPA, which requires DOE to utilize private industry to the fullest extent possible in each aspect of the transportation of spent nuclear fuel to a repository. These plans do not apply to shipment of naval spent nuclear fuel. The U.S. Department of the Navy would be responsible for transporting its spent nuclear fuel to the repository. Shipments of naval spent nuclear fuel would comply with the applicable regulations of the U.S. Department of Transportation, states, local governments, and Native American tribes. Shipping casks used for naval spent nuclear fuel would be certified by the U.S. Nuclear Regulatory Commission.

M.3.1 ACQUISITION OF CONTRACTOR SERVICES FOR WASTE ACCEPTANCE AND TRANSPORTATION

As required by Section 137 of the NWPA, DOE would utilize private industry to the fullest extent possible in each aspect of the transportation of spent nuclear fuel to the proposed repository. In September 1998, DOE published a draft Request for Proposal, *Acquisition of Waste Acceptance and Transportation Services for the Office of Civilian Radioactive Waste Management* (DIRS 153487-DOE 1998, all). According to this draft document, DOE would purchase services and equipment from *Regional Servicing Contractors* who would perform waste acceptance and transportation operations. If the site was approved, DOE has identified key areas of the draft Request that would require further refinement before a final solicitation, including the method of contract financing and payment. There are also specific areas related to the physical transfer of spent nuclear fuel that would be addressed before a final request. DOE is reviewing these areas and, accordingly, revising its strategy to acquire and deploy the transportation infrastructure to begin receiving shipments at Yucca Mountain in 2010. DOE would review and update the request and reissue it for further comment before issuing a final request.

As stated in the draft Request, DOE could use competitive fixed-price type or fixed-rate contracting. In addition, during several decades of operations, DOE would issue several Requests for Proposal with multiple awards, dividing the country into four regions, perhaps based on the four Nuclear Regulatory Commission regions, with one contractor to service each region. A *Regional Servicing Contractor* would receive no more than two regional servicing contracts. Regional Servicing Contractors would:

- Comply with applicable Federal (Nuclear Regulatory Commission, and U.S. Department of Transportation), state, local, and Native American regulations
- Work with utilities (generators) to determine the best way to service a site and integrate site planning into a regional servicing plan
- Provide all hardware, including transportation casks, canisters, and ancillary lifting equipment
- In conjunction with DOE, interact with state, local, and Native American governments as appropriate
- Provide all acceptance and transportation services necessary to move spent nuclear fuel from the generator sites to the proposed repository

DOE would retain responsibility for policy decisions, state and Native American relations, final route selection, and implementation of Section 180(c) of the NWPA. These activities would not be delegated to the Regional Servicing Contractor.

Under current draft plans, contracts would have three phases:

- Phase A: Development of site-specific and regional servicing plans and fixed-price bids, followed by authorization of one Regional Servicing Contractor per region to continue work into Phase B
- Phase B: Mobilization of transportation services, finalization of transportation routes and training, acquisition of transportation equipment (through lease or purchase)
- Phase C: Actual performance of acceptance activities and movement of spent nuclear fuel and high-level radioactive waste once a repository became operational

The plan for the acceptance of spent nuclear fuel would be consistent with DOE obligations under the Standard Contract (10 CFR Part 961). Acceptance schedules would be based on receiving spent nuclear fuel from generators consistent with allocations based on the acceptance priority ranking specified in the Standard Contract. In developing site-specific servicing plans, contractors could propose alternative schedules to enhance cask utilization and improve operational efficiency. The alternative schedules would require the consent and approval of the utility involved.

M.3.2 OPERATIONAL PRACTICES

Each Regional Servicing Contractor would be required to prepare a transportation plan that described the Contractor's operational strategy and delineated the steps it would implement to ensure compliance with all regulatory and other DOE requirements. This would include identification of proposed routes and associated routing considerations, coordination and communication with all participating organizations and agencies, and interactions with appropriate Federal, Native American, and state organizations. DOE would provide the draft transportation plan from each Regional Servicing Contractor selected for Phase B work to the states and tribes through whose jurisdictions spent nuclear fuel would be shipped for review and comment.

The draft Request for Proposal sets forth DOE requirements for the overall approach for transportation operations (DIRS 153487-DOE 1998, Section C, Appendix 8). These requirements are either based on or in addition to other Federal, state, or Native American regulatory requirements. Many of these practices are followed for shipments of transuranic waste to the Waste Isolation Pilot Plant in New Mexico. This section summarizes the requirements. In addition, DOE is developing transportation practices it can apply to all Department activities. The requirements or practices discussed in this section could be modified as appropriate to reflect these developing practices. In addition, DOE would implement requirements contained in applicable revisions to Federal, state, Native American, and local laws and regulations that applied to shipment of spent nuclear fuel and high-level radioactive waste.

These practices pertain primarily to activities associated with the Regional Servicing Contractor and DOE. In addition, the utility or Federal facility from which spent nuclear fuel or high-level radioactive waste would be shipped would play an important role in the transportation process. It would provide trained operators to load shipping casks and prepare them for shipment. This would include initial cask (or canister) receipt at the facility, completion of receipt inspections, and preparation activities before loading. The cask would be loaded according to the specifications listed on the Certificate of Compliance issued by the Nuclear Regulatory Commission for the particular cask. After the cask was loaded and placed on the transporter, preshipment inspections and tests would be conducted. These would include such things as leak tests, checking to ensure all lid bolts were fastened properly, and checking to see that impact limiters were attached properly. The cask would be checked for surface contamination and to ensure that radiation levels were within regulatory limits. The shipper, DOE, would be provided with the information necessary to complete the shipping papers. In the case of a highway shipment, the vehicle, load, and driver would be inspected according to procedures described in the Commercial Vehicle Safety Alliance North American Uniform Standard Out-of-Service Criteria (DIRS 156422-CVSA 2001, all) (see 49 CFR Part 397).

M.3.2.1 Planning and Mobilization

The requirements described in this section are associated primarily with Phase A and Phase B planning and mobilization activities. These requirements would be used to establish the baseline operational organization and practices to be used during early mode and route identification, fleet planning and acquisition, carrier interactions, and operations.

M.3.2.1.1 *Transportation Mode Selection*

The Regional Servicing Contractor would receive a current Delivery Commitment Schedule (described in 10 CFR Part 961) and other supporting data for each site to be serviced. These documents would provide information to support site-specific recommendations for the transportation mode, based on generator facility capabilities. This information could include a specific mode reflecting a generator’s preference. In this case, the Regional Servicing Contractor would have to provide transportation systems compatible with this mode designation unless other infrastructure constraints made the generator’s designation impractical. Suitability of the near-site infrastructure would be based on an evaluation of existing roads, railroads, bridges, etc., without modifications or upgrades. As stated in the draft Request for Proposal, DOE prefers to use rail transport wherever practical (DIRS 153487-DOE 1998, p. C-14). In addition, the Contractor would be required to use dedicated trains for shipments whenever such trains were determined to provide improvements in safety and enhance the efficiency of transport operations and logistics.

M.3.2.1.2 *Route Selection*

All routes used to transport radioactive waste would comply with applicable regulations of the U.S. Department of Transportation and the Nuclear Regulatory Commission. Under current planning, the Regional Servicing Contractor would have to meet the additional requirements described below when identifying proposed transportation routes (DIRS 153487-DOE 1998, all). The Contractor would consult with the other Regional Servicing Contractors as appropriate to ensure continuity and consistency of routes. All recommendations for pickup routes would be consistent with the suitability of the supporting infrastructure based on evaluations using existing roads, docks, bridges, channels, etc., without modification or upgrade, for highway routes, and would comply with the requirements in 49 CFR 397.101. After identifying a specific route, the Contractor would submit the route plan to DOE for approval. DOE would interact with states and Native American governments concerning these selections. With DOE approval, the Contractor would then submit the route plans to the Nuclear Regulatory Commission in accordance with 10 CFR 73.37(a)(7). (Actual route selection and submission to the Commission would occur 1 or more years before a route’s use for shipment. Though the EIS applied the selection methodology described in this appendix, actual routes could differ from those used in the analyses.)

Almost all DOE commercial spent nuclear fuel highway shipments under a Regional Servicing Contract would be Highway Route-Controlled Quantities of Radioactive Material. Therefore, U.S. Department of Transportation routing rules (49 CFR 397 Subpart D) would apply. As specified in 49 CFR 397.101(b)(1), the Regional Servicing Contractor would have to use preferred routes that reduced time in transit.

The Regional Servicing Contractor would identify rail transportation routes in conjunction with the appropriate rail carriers. Because railroad companies determine the routing of shipments, the Contractor would rely on the rail carrier to provide primary and secondary route recommendations consistent with safe railroad operating practices. Guidelines would include consideration of track classification to ensure use of the highest rated track to the greatest extent possible, and maximum use of *key routes* as described in *Recommended Railroad Operating Practices for Transportation of Hazardous Materials* (DIRS 155658-AAR 2000, all), which requires specific inspection, maintenance, and operating procedures for key routes.

The Regional Servicing Contractor would identify barge and heavy-haul truck transportation routes in conjunction with the respective carriers and, as appropriate, discussions with state, local, U.S. Coast Guard, and U.S. Army Corps of Engineers representatives and Port Captains. Discussions about barge shipments would include development of a marine transportation plan, specific barge/cask interface requirements, availability of tug services, and identification of preshipment inspections and marine surveys. The heavy-haul truck route identification process would be in conjunction with, and in compliance with, the requirements of the routing agency of the state(s) in which shipments would occur and the applicable U.S. Department of Transportation requirements.

The Regional Servicing Contractor would be responsible for conducting studies or analyses necessary to support route recommendations, including identification of intermodal transfer locations, if needed. The Contractor would also be responsible for obtaining the necessary permits or authorizations, including payment of fees, rents, or leases associated with barge or heavy-haul truck operations.

M.3.2.1.3 *Safe Parking Areas*

Highway shipments of spent nuclear fuel or high-level radioactive waste could be delayed en route due to mechanical problems, weather or road conditions, or other unanticipated problems. In anticipation of such events, the Regional Servicing Contractor would identify safe parking areas along each highway route as part of the route determination process. The key factors in selecting a safe parking area would be (1) the desirability of a particular type of parking area and (2) the ability of the driver and crew to reach that parking area under different types of unanticipated delays or emergencies. The prioritized criteria for the identification and selection of safe parking areas include the following:

1. DOE facilities (as identified by DOE)

2. Specific places designated by DOE or the state; for example:

   - U.S. Department of Defense facilities
   - Truck stops
   - Rail sidings (with railroad concurrence)
   - Ports of entry
   - State highway service facilities
   - National Guard facilities

3. If none of the parking options under the first two choices could be reached safely, criteria for the avoidance of particular types of areas would be applied to select a suitable safe parking area. Although it might not be possible to locate a parking site that met all of the following criteria, the plan would be to avoid the following types of potential parking locations:

   - Highly populated areas
   - Hospitals and schools
   - Residential areas

- Areas with numerous pedestrians
- Heavily industrialized areas
- Areas with difficult access
- Crowded parking areas (such as shopping malls)
- Highway shoulders

Safe parking areas should also:

- Provide adequate separation from other vehicles carrying hazardous materials
- Facilitate required security (such as maintaining observation of the vehicle)
- Provide adequate driver and crew services

M.3.2.1.4 *Adverse Weather, Road, and Rail Conditions*

The Regional Servicing Contractor would obtain route weather forecast information as part of the preshipment planning and notification and shipment dispatching process. At the time of departure, current weather conditions, the weather forecast, and current travel conditions would have to be acceptable for safe vehicle operation. If these conditions were not acceptable, the shipment would be delayed until travel conditions became acceptable. The driver and crew would concur with the decision to dispatch the shipment(s). Shipments would not travel when severe weather conditions developed along routes or adverse road conditions made travel hazardous. Driver and crew communications with the control center would provide advance warning of potential adverse conditions along the route. If the shipment encountered unanticipated severe weather or adverse road conditions, the driver and crew would contact the control center to coordinate routing to a safe parking or stopping area if it became necessary to delay the shipment until conditions improved.

DOE would provide the Regional Servicing Contractor with notification of road or highway construction that could temporarily affect the planned route. DOE would obtain road and highway conditions and information on anticipated construction through consultation with the states along the planned route. Long-range highway construction planning information provided by state highway departments would be given to the Contractor. This information would aid in confirming final shipping schedules and determining if short-term alternative route planning and additional approvals by the states or the Nuclear Regulatory Commission would be required before initiating the shipments.

Rail carriers use train control and monitoring systems to identify the location of their trains within the rail system and to make informed decisions based on this information to avoid or minimize potential weather-related or track-condition risks. Under 49 CFR 174.20, the carrier can impose local restrictions on transportation when local conditions make travel hazardous. Adverse operating conditions can be reported to the DOE shipper through several means (for example, communications with the carrier or information provided by state, Native American, or local authorities).

M.3.2.1.5 *Tracking and Communication*

Shipment tracking and preshipment and communications en route would be key responsibilities of the Regional Servicing Contractor. A system that provided the necessary tracking and communications with DOE, affected governments, other Regional Servicing Contractors, and the repository would be in place at all times.

The Regional Servicing Contractor would provide continuous real-time position tracking for all shipments using the TRANSCOM satellite tracking system or an equivalent system approved by DOE. The system would provide DOE and the Contractor with a continuous, centralized monitoring and communications capability. The Contractor would be responsible for acquisition, installation, maintenance, and security of the tracking system equipment.

The Regional Servicing Contractor would develop detailed procedures to be followed in the event that the tracking system was temporarily not available. The procedures would be based on a telephone call-in system that provided for the driver or other crew member reporting the shipment location to DOE on a regular basis and before crossing state and tribal borders.

In addition to the satellite tracking system, the Regional Servicing Contractor would furnish and equip all tractors and rail escort cars with communications equipment.

M.3.2.1.6 *Carrier Management Plan*

The Regional Servicing Contractor would be responsible for selecting and using transportation carriers that complied with all applicable regulatory and DOE operational transportation requirements. The Contractor would require all carrier subcontractors to provide a carrier management plan that addressed the following areas:

- Management organization, including subcontractor management
- Driver and crew screening and hiring
- Driver and crew operations and safety training and refresher training
- Maintenance and inspection of personnel qualifications
- Maintenance program, including procedures and inspections
- Pretrip and posttrip inspection requirements
- Maintenance en route or breakdown repair or equipment replacement
- Emergency or incident response training and refresher training
- Accident or incident reporting system
- Policy for imposition of specific driver and crew penalties
- Substance abuse policy, including screening tests
- Security plan
- Quality assurance plan
- Safety program
- Records management system

M.3.2.1.7 *Carrier Personnel Qualifications*

Carriers would develop and maintain a qualification and training program that meets U.S. Department of Transportation and Nuclear Regulatory Commission requirements for drivers, engineers, crew, and security personnel. For truck drivers, qualifications include being at least 21, meeting physical standards, having a commercial driver's license, and successfully completing a road driving test in the shipment vehicle. In addition, drivers must have training on the properties and hazards of the material being transported, as well as the procedures to follow in the event of an emergency. Locomotive engineers must meet the Locomotive Engineer Certification requirements of 49 CFR Part 240, which include completing an approved training program. In addition to these requirements, driver and crew training would cover the following:

- Operation of the specific package tie-down systems

- Cask recovery procedures

- Use of radiation detection instruments

- Use of a satellite-based tracking system and other communications equipment
- Adverse weather and safe parking procedures
- First responder awareness training
- Radiation worker B (or equivalent) training
- Enhanced inspection standards as specified in the Commercial Vehicle Safety Alliance North American Uniform Standard Out-of-Service Criteria (DIRS 156422-CVSA 2001, Paragraph 5.0)
- The "Physical Protection of Irradiated Fuel in Transit, Training Program" (10 CFR 73, Appendix D), which includes security requirements

M.3.2.2 Shipment Operations

M.3.2.2.1 *Notice of Shipments*

Advance notice of DOE shipments, ongoing status of shipments, and other pertinent shipment information would be necessary to meet regulatory requirements [10 CFR Part 71.97, 10 CFR 73.37 (f), and 10 CFR 73.72]. This information would be used to support coordination of repository receipt operations, support emergency response capabilities, identify weather or road conditions that could affect shipments, identify safe parking locations, schedule needed inspections, and coordinate public information programs.

The Regional Servicing Contractor would provide projected shipping schedules to DOE. DOE would provide schedule information to the states and tribes based on specific approved routes approximately 6 months before the initiation of planned shipments.

M.3.2.2.2 *Inspections*

Inspections of highway shipments would be conducted at the points of origin and destination using the enhanced inspection standards of the Commercial Vehicle Safety Alliance (DIRS 156422-CVSA 2001, all). DOE selected the Commercial Vehicle Safety Alliance, an international organization of state and province officials responsible for the administration and enforcement of motor carrier safety laws, to develop an inspection and enforcement program specific to spent nuclear fuel, high-level radioactive waste, transuranics and other Highway Route-Controlled Quantities of Radioactive Material. The procedures developed under this program provide uniform standards for radiation surveys, inspection of drivers, shipping papers, vehicles, and casks. The procedures set higher standards for these shipments than are contained in the North American Inspection Standards, which are used to inspect all other types of shipments. The procedures are used to inspect a shipment at point of origin. A vehicle receives a special inspection decal, good only for that shipment, if it is defect-free according to the enhanced standards. The Commercial Vehicle Safety Alliance has trained state inspection personnel on the enhanced procedures, which are currently being applied to DOE shipments (DIRS 156703-FRA 1998, all) of transuranics and other Highway Route-Controlled Quantities of Radioactive Material.

Rail shipments would be inspected in accordance with 49 CFR 174.92 and the Federal Railroad Administration's High-Level Nuclear Waste Rail Transportation Inspection Policy. The policy states (DIRS 156703-FRA 1998, Appendix A):

> *Past rail shipping campaigns of high-level nuclear waste have shown that the nature of the potential hazards associated with radioactive materials elicits a relatively high degree of public awareness and*

concern in regard to transportation of the material. As a result, the Federal Railroad Administration developed and instituted an inspection policy for rail movements of this type of hazardous material. This policy sets inspection frequency criteria above and beyond that which may normally be necessary and is implemented for all known high-level nuclear waste shipments by rail.

In addition to pre- and postshipment inspections of the transport package and crew safety inspections en route of the transport vehicles, DOE anticipates that various states and tribes could require additional vehicle inspections when shipments entered their respective jurisdictions. For barge shipments, inspections and surveys would be in accordance with U.S. Coast Guard regulations (46 CFR Parts 90 to 105). Inspections en route would be scheduled using the satellite system and other position-reporting capabilities to notify appropriate jurisdictions of the approach of a shipment so state or tribal inspection officials could be available at designated points to perform the inspection with minimal disruption to operating schedules. Inspections for rail shipments would be coordinated with normal crew change locations wherever possible to minimize additional stops.

M.3.2.2.3 *Procedures for Delays En Route*

The Regional Servicing Contractor would be responsible for providing or having carriers provide drivers and crews with specific written procedures that clearly defined detailed actions the driver and crew would take in the event of various delays en route. These include unanticipated route conditions due to civil strife or other disruptions, traffic delays due to traffic accidents not directly involving the cask shipments, emergency road or rail construction, or delays caused by sudden or unanticipated weather conditions. Procedures would address notifications, maintaining security, selecting alternative routes or route detours, or moving to the nearest safe parking area.

M.3.2.2.4 *Procedures for Off-Normal Operations (Unrelated to Accidents, Incidents, or Emergencies)*

The Regional Servicing Contractor would be responsible for providing or having carriers provide drivers and crews with specific written procedures that clearly defined detailed actions that the driver and crew would take during off-normal events. These include, but are not limited to, mechanical breakdown, fuel problems, tracking system failure, and illness, injury, or other incapacity of the driver or a member of the crew. Procedures would address notifications, deploying appropriate hazard warnings, maintaining security, obtaining medical assistance, arranging for crew replacement or for maintenance, repair, or replacement of equipment, or recovery, as appropriate.

M.3.2.2.5 *Emergency or Incident Response*

The Regional Servicing Contractor would be responsible for providing or having carriers provide drivers and crews with specific written procedures that clearly defined detailed actions they would take in the event of an emergency or incident involving property damage, injury, or the release or potential release of radioactive materials. Procedures would comply with U.S. Department of Transportation guidelines for emergency response contained in the *2000 Emergency Response Guidebook* (DIRS 155776-DOT 2000, all) and would address the following:

- Emergency assistance to injured crew or others involved
- Identification and assessment of the situation
- Notification and communication requirements
- Securing the site and controlling access
- Technical help to first responders

M.3.2.3 Postshipment Activities

Postshipment activities would include inspections of each loaded transport casks and, after completion of unloading operations, maintenance or reconfiguration and preparation of the cask and other supporting transportation system equipment for temporary parking at the proposed repository or redeployment for more shipments.

M.3.2.3.1 *Postshipment Radiological Surveys*

Receiving facility operators would survey each cask and transporter on arrival and receipt at the proposed repository and, before initiating unloading operations, would determine if any contamination beyond the limits specified in 49 CFR 173.443 occurred during transit. In addition, the cask, its tie-downs, and associated transportation system hardware would be inspected visually to ensure that no physical damage occurred during transit.

DOE, as the shipper, would be responsible for reporting any contamination or damage to the Nuclear Regulatory Commission in accordance with 10 CFR 71.95. The Department would also be responsible for notifying the utility at whose facility the shipment originated and, with the utility, for initiating corrective actions. In addition to reports required for the Nuclear Regulatory Commission, the DOE Office responsible for repository operations would provide a report to DOE Headquarters describing the incident, including probable cause, and the corrective actions taken to prevent recurrence.

M.3.2.3.2 *Shipment of Empty Transportation Casks*

Except before their first use, shipments of all empty transportation casks would comply with the requirements of the Nuclear Regulatory Commission certificate of compliance or 49 CFR 173.427, whichever was applicable. Escort and security requirements, advance shipment notifications, continuous position tracking, and inspections en route would not apply to the shipment of empty transportation casks.

M.4 Cask Safety and Testing

M.4.1 TEST REQUIREMENTS FOR CASKS

The purpose of the Nuclear Regulatory Commission regulations applicable to the transportation of spent nuclear fuel and high-level radioactive waste materials to the proposed repository is to protect the public health and safety for normal and accident conditions of transport and to safeguard and secure shipments of these materials. Regulations in 10 CFR Part 71 require that casks for shipping spent nuclear fuel must be able to meet specified radiological performance criteria for normal transport and following a sequential series of tests that represent severe accident conditions. Meeting these requirements is an integral part of the safety assurance process associated with transportation casks. The ability of a design to withstand the test conditions can be demonstrated by comparing designs to similar casks, engineering analyses (such as computer-simulated tests), or by scale-model or full-scale testing. These tests include a 9-meter (30-foot) drop onto an unyielding flat surface, a 1-meter (40-inch) drop onto a vertical steel bar, exposure of the entire package to fire for 30 minutes, and immersion in 1 meter (3 feet) of water. In addition, an undamaged cask must be able to survive submersion in the equivalent pressure of 15 meters (50 feet) and 200 meters (650 feet) of water. Studies conducted by the Nuclear Regulatory Commission show that these test conditions simulate almost all observed or anticipated accidents (DIRS 101828-Fischer et al. 1987, all; DIRS 152476-Sprung et al. 2000, all; see Section M.4.2). For most accidents more severe than those represented by the test conditions, the Nuclear Regulatory Commission studies show that the radiological criteria for containment, shielding, and subcriticality are still satisfied. The studies also show that for the few severe accidents in which these criteria could be exceeded, only containment and shielding would be affected, and the regulatory criteria could be exceeded only slightly. The following paragraphs discuss each of these tests.

M.4.1.1 Nine-Meter Drop onto an Unyielding Surface

The first test in the accident sequence simulates impact. The test is specified as a 9-meter (30-foot) free fall onto an unyielding surface with the cask striking the target in the most damaging orientation. The free fall results in a final velocity of 48 kilometers (30 miles) per hour. Although this velocity is less than the expected speed of interstate highway traffic, the test is severe because the target surface is unyielding. This results in all the energy of the drop being absorbed by the cask. There is no such thing in nature as an unyielding surface. Striking an unyielding surface at 48 kilometers per hour, when all the impact energy is absorbed by the cask, is approximately equivalent to a 97-kilometer (60 mile)-per-hour impact with a “medium” hardness surface, such as shale or other relatively soft rock, and a 150-kilometer (90 mile)-per-hour impact with a “soft” surface, such as tillable soil.

M.4.1.2 One-Meter Drop onto a Steel Bar

The second test in the sequence simulates a cask hitting a rod or bar-like object that could be present in an accident. The test is specified as a 1-meter (40-inch) drop onto a 15-centimeter (6-inch)-diameter rod sitting on the unyielding surface. The cask must be in the orientation in which maximum damage would be likely. In addition, the bar must be long enough to cause maximum damage to the cask. The test frequently evaluates several impacts in which different parts of a cask strike the bar either by simulation or physical testing. This is to demonstrate that all parts of the cask would pass the test.

M.4.1.3 Fire Test

The third test in the sequence simulates a fire occurring after the two impacts described above. The test is specified as a 30-minute engulfing hydrocarbon fire with an average flame temperature of 800°C (1,472°F). The test requires the cask to be fully engulfed in the flame for the full 30 minutes. Following an actual severe accident a cask would probably be lying on the ground in a position such that it would not be fully engulfed.

M.4.1.4 Water Immersion Tests

The fourth and final test of the sequence is a shallow immersion test. The test cask (after being subjected to the two drops and the fire) must next be immersed in 1 meter (3 feet) of water. The purpose of this test is to ensure that water cannot leak into the cask.

An undamaged version of the cask must also be able to survive immersion in the equivalent of 15 meters (50 feet) of water [a pressure of about 1,500 grams per square centimeter (22 pounds per square inch)] to test for leakage. Furthermore, shipping casks designed to hold more than 1 million curies of radioactivity must be able to survive water pressure of about 20,000 grams per square centimeter (290 pounds per square inch) for 1 hour without collapse, buckling, or leaking. That pressure is equivalent to a depth of about 200 meters (650 feet). The purpose of this standard is to ensure that casks accidentally sunk on the outer continental shelf could be retrieved with their contents intact.

M.4.1.5 Acceptance Criteria

To be judged successful in meeting these tests [except the 200-meter (650-foot) submersion], a cask must not release more than limited amounts of radioactive material in 1 week. These release limits are set for each radionuclide based on dispersivity and toxicity. In addition, it must not emit radiation at a dose rate of greater than 1 rem per hour at a distance of 1 meter (3 feet) from the cask surface. Finally, the spent nuclear fuel or high-level radioactive waste in the cask must not be capable of undergoing a nuclear chain reaction, or criticality, as a result of the test conditions. A recent study by Sandia National Laboratories for the Nuclear Regulatory Commission determined that less than 1 in 10,000 transportation accidents involving casks that satisfy the performance requirements of the Commission regulations would be severe enough to cause a release from a spent nuclear fuel cask (DIRS 152476-Sprung et al. 2000, pp. 7-73 to 7-76).

M.4.1.6 Tests Using Models

The ability of a cask to survive these tests can be demonstrated in several ways. First, an actual, full-size model of the cask can be subjected to all the tests in the sequence. As an alternative, the tests can be applied to small models of the casks (typically half- or quarter-scale). Finally, cask designs can be compared to previous licensed designs or analyzed with computer models. The Nuclear Regulatory Commission decides what level of physical testing or analysis is necessary for each cask design. Because the Commission generally accepts the results of scale-model testing, expensive full-scale testing of entire spent fuel casks is rarely conducted, although such tests are sometimes required for specific cask components. For example, the Commission could require quarter-scale drop tests for a particular cask design but full-scale tests of the cask's impact limiters (cushioning material typically attached to each end). Computer analysis could be sufficient for meeting the fire test and for criticality control.

M.4.2 STUDIES OF TRANSPORTATION ACCIDENT RISK

This section presents information from the recent report to the Nuclear Regulatory Commission from the Commission staff, "Transportation Risk Studies" (DIRS 155562-NRC 2000, all).

Federally funded studies of nuclear waste transportation accident risks have concluded that current regulations provide an adequate margin of safety. For example, the Nuclear Regulatory Commission first evaluated impacts on public health and safety from transportation activities in the *Final Environmental Impact Statement on the Transportation of Radioactive Materials by Air and Other Modes* (DIRS 101892-NRC 1977, all). This document examined impacts from transportation by land, air, and sea transport modes under incident-free and accident conditions.

Considering the information developed and received, and the safety record associated with the transportation of radioactive material, the Commission determined that the regulations then in place were adequate to protect the public against unreasonable risk from the transport of radioactive materials, and that no immediate changes in the regulations were needed to improve safety (46 *FR* 21619; April 13, 1981). The U.S. Department of Transportation also relied on DIRS 101892-NRC (1977, all) to assess the impact of radioactive material transportation under its Hazardous Materials regulations (49 CFR Subchapter C, Parts 171 to 180).

In the mid-1980s, several shipment campaigns were initiated to return spent nuclear fuel from the West Valley Demonstration Project in western New York to the originating utilities. These campaigns drew considerable public interest, and questions focused on the difficulty in comparing the Nuclear Regulatory Commission's spent fuel cask accident standards with actual accident conditions. These standards are expressed as a series of hypothetical tests and acceptance criteria described in 10 CFR 71.73. The Commission addressed the level of safety provided by its regulations under accident conditions in a study, which is frequently referred to as the *Modal Study* conducted for the Commission by Lawrence Livermore National Laboratory [*Shipping Container Response to Severe Highway and Railway Accident Conditions* (DIRS 101828-Fischer et al. 1987, all)].

To elaborate on the DIRS 101892-NRC (1977, all) spent nuclear fuel shipment accident risk estimate, the Modal Study included an assessment of the probabilities and forces associated with severe transportation accidents. In addition, the Modal Study examined transport cask responses to accidents by using finite element modeling of generic cask responses to accident forces. The results indicated that spent nuclear fuel shipment risks were about one-third those estimated in DIRS 101892-NRC (1977, p. 5-51 to 5-53). From the Modal Study, the Nuclear Regulatory Commission concluded that the study clearly bounded spent nuclear fuel shipment risks, which supported the Commission's previous decision that there was no need to change transportation regulations to improve safety.

Another recent study by Sandia National Laboratories for the Nuclear Regulatory Commission, the *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et al. 2000, all) examined whether the original Modal Study risk estimates bounded those for the anticipated shipment campaigns. Like the Modal Study, this study calculated the risks for spent nuclear fuel shipments under incident-free and accident conditions but, unlike that study, considered such factors as the design, enrichment, burn-up, and cooling time of fuel currently anticipated to be shipped; the capacity and designs of newer casks; and current population densities along road and rail routes. The results of this study continue to show that accident risk estimates are much less than those estimated in DIRS 101892-NRC (1977, all).

An ongoing transportation accident risk study, the *Package Performance Study* focuses on spent nuclear fuel cask responses to severe transportation accidents (see 65 *FR* 45629; July 24, 2000). The objective of this study is to address remaining spent nuclear fuel transportation issues from the Modal Study (DIRS 101828-Fischer et al. 1987, all) and the *Reexamination of Spent Fuel Shipment Risk Estimates* (DIRS 152476-Sprung et al. 2000, all), using a public participation approach to solicit public and stakeholder interests in developing the study's scope and parameters for review. Further, whereas the earlier studies were analytical in nature, the Package Performance Study will consider the use of physical testing to address issues, where appropriate. Risk insights obtained using current analysis techniques, physical testing, and through interaction with stakeholders and the public, will support the Nuclear Regulatory Commission's ongoing efforts to ensure that its regulatory actions are sensitive to risk and effective.

M.4.3 RESULTS FROM PREVIOUS CRASH TESTS

U.S. laboratories, with British assistance, have staged severe truck and rail accidents to study the response of full-scale spent nuclear fuel casks. Those tests, which were designed primarily to verify computer models, yielded films and photographs that have been widely cited as strong evidence of nuclear waste transportation safety, because they illustrate the robustness of these casks in accidents. Sandia National Laboratories conducted four crash tests of U.S. spent nuclear fuel casks during 1977 and 1978 (DIRS 155792-Yoshimura 1978, all). In the first test, a truck carrying a 20-metric-ton (22-ton) cask was crashed into a hard, massive, earth-backed concrete wall at 97 kilometers (60 miles) per hour, causing very little damage to the cask. The same cask was loaded onto another truck and driven into the wall at 135 kilometers (84 miles) per hour, again causing minor cask damage. In the third test, a locomotive traveling 130 kilometers (81 miles) per hour struck a 23-metric-ton (25-ton) cask on a truck trailer that was parked across the tracks. The fourth test involved crashing a railcar carrying a 67-metric-ton (74-ton) spent nuclear fuel cask into the hard, massive, earth-backed concrete wall, and the same cask and railcar were then engulfed in a jet fuel fire. After about 90 to 100 minutes, or three times the duration of the regulatory test, the fire was stopped when evidence of damage to the shield casing was observed. Although the observed damage could have reduced shielding effectiveness, it would not have impaired containment capability. The tests were intended to verify computer simulation programs used for structural analysis. They were not intended to rigorously assess containment capability, nor were the casks instrumented to do so. The experts who conducted the tests, however, made some qualitative judgments about cask performance. According to Sandia, none of the tests would have released hazardous levels of radioactivity if the casks had contained spent nuclear fuel (DIRS 155792-Yoshimura 1978, all).

A British train crash demonstration, conducted in 1984, involved a locomotive weighing 140 metric tons (154 tons) pulling three 33-metric-ton (36-ton) passenger cars at 160 kilometers (100 miles) per hour. The train struck a British Magnox spent nuclear fuel cask weighing 48 metric tons (53 tons) that had been placed on the tracks in what was believed to be its most vulnerable position. The cask held 3 metric tons (3.3 tons) of steel bars meant to simulate spent nuclear fuel. According to a report on the demonstration, the cask was positioned "so that a valve would be in the impact zone and so that the wheels and tow-hook on the locomotive would inflict maximum damage to the lid bolts" (DIRS 155791-Blythe et al. 1986, all). Extensive monitoring of the demonstration indicated that almost no cask pressure was lost and that no radioactivity would have been released by the crash. Measurements showed that the train impact was substantially less severe than the impact of the 9-meter (30-foot) drop test onto an unyielding surface. A report on the British train crash demonstration concluded that computer models could predict crash forces on spent nuclear fuel casks "with a high degree of confidence" (DIRS 155791-Blythe et al. 1986, all).

M.5 Emergency Response

M.5.1 ROLES AND RESPONSIBILITIES

As with any emergency situation in their jurisdictions, state and Native Americans governments have the primary responsibility to respond to accidents involving radioactive materials and to protect the public health and safety. State, tribal, and local emergency response personnel are the first to respond to hazardous material accidents. On arriving at the scene, first responders determine the presence or identification of hazardous materials, cordon off contaminated areas, initiate protective actions, and call for assistance from other personnel as necessary. Local responders usually contact state or tribal public health agencies. Many of those agencies have personnel trained to conduct radiological tests at the site to determine if there has been a release of radioactive material.

State, Native American, and local governments can request assistance from Federal agencies. An extensive Federal program exists to assist states and tribes in the event of an accident involving spent nuclear fuel or high-level radioactive waste. Seventeen Federal agencies participate in the program and are available to assist, if requested. A Lead Federal Agency, as defined by the "Federal Radiological Emergency Response Plan" (61 *FR* 20944; May 8, 1996), is responsible for leading and coordinating Federal on-scene actions and assisting state, tribal, and local governments in determining measures to protect life, property, and the environment. If requested, the Lead Federal Agency would ensure that other Federal agencies assisted in implementing protective actions. The Lead Federal Agency can change for different stages of an emergency.

DOE is responsible for developing policy and guidance for emergency planning, management, training, and response to an accident involving its shipments. The Department has several programs available to provide assistance to state, Native American, and local governments in response to radioactive material accidents. The Radiological Assistance Program, for example, provides trained personnel with equipment to evaluate, assess, advise, and assist in the mitigation and monitoring of potential immediate hazards associated with a transportation accident. As part of the program, DOE maintains eight Regional Coordinating Offices across the country that are staffed 24 hours a day, 365 days a year. The staff consists of nuclear engineers, health physicists, industrial hygienists, public affairs specialists, and other personnel who provide field monitoring, sampling, decontamination, communications, and other services, as requested.

DOE's Radiation Emergency Assistance Center/Training Site (REAC/TS) focuses on providing rapid medical attention to people involved in radiation accidents. REAC/TS maintains a 24-hour response center to provide direct support, including deployable equipment and personnel trained and experienced in the treatment of radiation exposure, to assist Federal, state, tribal, and local organizations.

M.5.2 ACTIONS TAKEN IN AN EMERGENCY SITUATION

During an emergency in which the carrier or escorts could communicate through the satellite tracking system or by phone if the system was not available, the carrier would contact DOE, and DOE would contact the state or tribe (who would contact the local responders), the Nuclear Regulatory Commission, and the U.S. Department of Transportation. When the first responders arrived, the carrier would assist as outlined in its emergency response plan. The first responders would investigate the potential presence of radioactive material, treat injuries, protect themselves and the public, and secure the area. As noted above, first responders would determine further appropriate emergency response actions, because they would be in charge of the accident scene. The roles and responsibilities of those who would respond to requests for assistance are described above.

If neither the carrier nor the escorts could communicate, the first responders arriving at the scene would still have information available about the shipment, such as the name of the shipper, the type of material being transported, and the telephone number to call in an emergency. This information would have been provided to the state, tribal government, or local law enforcement personnel in accordance with Nuclear Regulatory Commission regulations during the preshipment planning process and in the advance notification of shipments. In addition, the information would be available in the shipping papers accompanying the shipment, and from the labels, markings, and placards associated with the shipment. The first responders would assess the accident scene and call for state, tribal, and Federal assistance as necessary.

M.6 Technical Assistance and Funding of Emergency Response Training for Local and Native American Governments

Section 180(c) of the NWPA requires DOE to provide technical assistance and funds to states for training public safety officials of appropriate units of local and Native American governments through whose jurisdictions the Department planned to transport spent nuclear fuel or high-level radioactive waste. The training of public safety officials would cover procedures required for safe routine transportation of these materials and for dealing with emergency response situations.

DOE is responsible for implementing Section 180(c). DOE published a Notice of Revised Proposed Policy and Procedures (63 *FR* 23753; April 30, 1998) based on comments received on several previous *Federal Register* notices. In the Proposed Action proceeded, DOE would either update the Policy and Procedures as a Final Policy, or could promulgate regulations.

The following list provides selected highlights of the Notice of Revised Proposed Policy and Procedures:

- DOE would implement Section 180(c) through a grants program. DOE would administer the grants, which would be specific to the Section 180(c) program. The Department would adopt, to the extent practicable, any future DOE-wide standardization of assistance to states and tribes for the Department’s radioactive materials shipments. This could include standardization of funding mechanisms, training standards, equipment purchases, and definition of technical assistance.

- DOE anticipates that it would know approximately 5 years before shipments occurred, the states or Native American, lands through which the shipments would travel, even if exact routes had not been selected. Using this information, DOE would notify those jurisdictions about their eligibility under Section 180(c).

- DOE has expanded eligibility to include those jurisdictions where a route carrying spent nuclear fuel and high-level radioactive waste shipments constitutes the border between two jurisdictions (for example, between a state and tribal lands, or between two states).

- For emergency response procedures, DOE would provide funding and technical assistance to eligible jurisdictions to address incremental training requirements resulting from spent nuclear fuel and high-level radioactive waste shipments. Specifically, the Department would provide funding and technical assistance for eligible jurisdictions to obtain and maintain awareness-level training for local response jurisdictions in the increment specific to radioactive materials shipments. In addition, to the extent funds were available, the assistance could be used to obtain an enhanced level of emergency response capability to include operations-level training, technical-level training, and the corresponding refresher training, all in an increment specific to radioactive materials shipments.

- For safe routine transportation procedures, DOE would provide funding and technical assistance to eligible jurisdictions to prepare for safety and enforcement inspections of spent nuclear fuel and high-level radioactive waste shipments and for access to satellite tracking information.

- The application process should take about a year. A one-time planning grant of $150,000 would be provided to eligible states and tribal jurisdictions for determining training and funding needs and for preparing an application in about 2006 (4 years before shipments began). DOE expects the application to include a 5-year plan detailing how the funds would be spent each year. In about 2007, the base grant for planning and coordination would be provided. In about 2008 to 2010, funds would be provided for training and the purchase of equipment. Local governments could not receive Section 180(c) grants or technical assistance directly from DOE.

- DOE would allow a variety of activities that an applicant might consider appropriate for training under Section 180(c). For example, it would be the applicant's decision who received training and which organization would administer the training. The Notice of Revised Proposed Policy and Procedures strengthens the requirement that first responders be the recipients of the awareness-level training. In addition, an applicant would be able to budget as much as 25 percent of its total Section 180(c) funds to purchase appropriate (training-related) equipment for the 2 years prior to shipment. After that, the applicant would be able to budget as much as 10 percent of the total Section 180(c) funds to purchase equipment.

M.7 Physical Protection of Spent Nuclear Fuel in Transport

Spent nuclear fuel contains small concentrations of fissile plutonium (generally less than 1 percent). If chemically separated from the spent nuclear fuel and refined, some of this plutonium could be used to produce explosive nuclear devices. To protect against this potential, regulations are established to ensure protection of shipments from illegal diversion. Because the fissile material is in low concentration and a difficult-to-retrieve form, the threat of diversion of a spent nuclear fuel shipment to obtain these materials would be slight.

In addition, shipments must be protected from sabotage. Initial studies of the effects of sabotage on spent nuclear fuel casks suggested the possibility of severe consequences. Although later studies and experiments found these initial studies to overpredict potential consequences, these initial predictions led the Nuclear Regulatory Commission to develop a set of rules specifically aimed at protecting the public from harm that could result from sabotage of spent nuclear fuel casks. Known as physical protection or safeguard regulations (10 CFR 73.37), these security rules are distinguished from other regulations that deal with issues of safety affecting the environment and public health. The objectives of the safeguard regulations are to:

- Minimize the possibility of sabotage
- Facilitate recovery of spent nuclear fuel shipments that could come under control of unauthorized persons

To achieve these objectives, the Nuclear Regulatory Commission safeguard rules require:

- Advance notification of each shipment to the Nuclear Regulatory Commission, the states, and Native American governments (see Section M.2.5)
- The licensee to have current procedures to cope with safeguard emergencies
- Instructions for escorts on how to determine if a threat exists and how to deal with it
- Maintenance of a communications center to continually monitor the progress of each shipment
- A written log describing the shipment and significant events during the shipment
- Advance arrangements with law enforcement agencies along the route
- Advance route approval by the Nuclear Regulatory Commission
- Avoidance of intermediate stops to the extent practicable
- At least one escort to maintain visual surveillance of the shipment during stops
- Shipment escorts to report status on a regular basis
- Armed escorts in heavily populated areas
- Onboard communications equipment
- Protection of specific shipment information

The expected threat of sabotage is based on several factors, including the desirability of attacking a spent nuclear fuel cask, availability of devices that a saboteur could use and the portability of such devices, skills required to use selected devices, and capability of the device to damage a robust spent nuclear fuel cask.

The safety features included in the design of a spent nuclear fuel cask that provide containment, shielding, and thermal protection also provide protection against sabotage. The casks would be massive. The spent nuclear fuel in a cask would typically be only about 10 percent of the gross weight; the remaining 90 percent would be shielding and structure.

Specific test programs have been conducted (DIRS 156313-Sandoval et al. 1983, all; DIRS 101921-Schmidt, Walters, and Trott 1982, all) to determine the nature and quantities of material that could be released from a spent nuclear fuel cask in sabotage events. These test programs confirmed that earlier studies (DIRS 155054-Finley et al. 1980, all) over-predicted potential consequences. The results of the tests indicate that the regulations, which were based on the earlier, more conservative estimates, are adequate to protect the public.

The Nuclear Regulatory Commission, along with other Federal agencies, continually monitors and evaluates threat assessments, which would enable revision of the regulations, if necessary.

M.8 Liability

The Price-Anderson Act [Section 170 of the Atomic Energy Act, as amended (42 U.S.C. 2011 *et seq.*)] provides indemnification for liability for nuclear incidents that apply to the proposed Yucca Mountain Repository. The following sections address specific details or provisions of the Act.

M.8.1 THE PRICE-ANDERSON ACT

In 1957, Congress enacted the Price-Anderson Act as an amendment to the Atomic Energy Act to encourage the development of the nuclear industry and to ensure prompt and equitable compensation in the event of a nuclear incident. Specifically, the Price-Anderson Act establishes a system of financial protection for persons who may be liable for and persons who may be injured by a nuclear incident. The purpose of the Act was (1) to encourage growth and development of the nuclear industry through the increased participation of private industry, and (2) to protect the public by ensuring that funds are available to compensate victims for damages and injuries sustained in the event of a nuclear incident. Congress renewed and amended the indemnification provisions in 1966, 1969, 1975, and 1988. The 1988 Price-Anderson Amendments Act extended the Act for 14 years until August 1, 2002 (Public Law 100-408, 102 Stat. 1066). DOE has recommended that Congress extend the Act in substantially the same form [see *Report to Congress on the Price-Anderson Act* (DIRS 155789-DOE 1999, all)].

M.8.2 INDEMNIFICATION PROVIDED BY THE PRICE-ANDERSON ACT

DOE must include an agreement of indemnification in each DOE contract that involves the risk of a nuclear incident. This indemnification (1) provides omnibus coverage of all persons who might be legally liable, (2) indemnifies fully all legal liability up to the statutory limit on such liability (currently $9.43 billion for a nuclear incident in the United States), (3) covers all DOE contractual activity that could result in a nuclear incident in the United States, (4) is not subject to the usual limitation on the availability of appropriated funds, and (5) is mandatory and exclusive.

M.8.3 LIABILITY COVERED AND LIABILITY EXCLUDED BY THE INDEMNITY

The Price-Anderson Act indemnifies liability arising out of or resulting from a nuclear incident or precautionary evacuation, including all reasonable additional costs incurred by a state or a political subdivision of a state, in the course of responding to a nuclear incident or a precautionary evacuation. It excludes (1) claims under state or Federal worker compensation acts of employees or persons indemnified who are employed at the site of and in connection with the activity where the nuclear incident occurs, (2) claims arising out of an act of war, and (3) claims involving certain property located on the site.

M.8.4 DEFINITION OF A NUCLEAR INCIDENT UNDER THE PRICE-ANDERSON ACT

A *nuclear incident* is any occurrence, including an extraordinary nuclear occurrence, causing bodily injury, sickness, disease, or death, or loss of or damage to property, or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or byproduct material (42 U.S.C. 2014).

M.8.5 PROVISIONS FOR A PRECAUTIONARY EVACUATION

A *precautionary evacuation* is an evacuation of the public within a specified area near a nuclear facility or the transportation route in the case of an accident involving transportation of source material, special nuclear material, byproduct material, spent nuclear fuel, high-level radioactive waste, or transuranic waste. It must be the result of an event that is not classified as a nuclear incident but poses an imminent danger of injury or damage from radiological properties of such nuclear materials and causes an evacuation. The evacuation must be initiated by an official of a state or a political subdivision of a state who is authorized by state law to initiate such an evacuation and who reasonably determined that such an evacuation was necessary to protect the public health and safety.

M.8.6 AMOUNT OF INDEMNIFICATION

The Price-Anderson Act establishes a system of private insurance and Federal indemnification to ensure compensation for damage or injuries suffered by the public in a nuclear incident. The current amount of $9.43 billion reflects a threshold level beyond which Congress would review the need for additional payment of claims in the case of a nuclear incident with catastrophic damage. The limit for incidents occurring outside the United States is $100 million and requires the nuclear material to be owned by and under contract with the United States.

M.8.7 INDEMNIFIED TRANSPORTATION ACTIVITIES

DOE indemnifies any nuclear incident arising in the course of any transportation activities conducted in connection with a DOE contractual activity, including transportation of nuclear materials to and from DOE facilities.

M.8.8 COVERED NUCLEAR WASTE ACTIVITIES

The indemnification specifically includes nuclear waste activities that DOE undertakes involving the storage, handling, transportation, treatment, disposal of, or research and development on spent nuclear fuel, high-level radioactive waste, or transuranic waste. It covers liability for accidents that could occur while spent nuclear fuel and high-level radioactive waste was in transit from nuclear powerplants to the proposed repository, at a storage facility, or at the repository. If a DOE contractor or other person indemnified was liable for the nuclear incident or a precautionary evacuation resulting from its contractual activities, that person would be indemnified for that liability. While DOE's own tort liability would be determined under the Federal Tort Claims Act, DOE could use contractors to transport spent nuclear fuel and high-level radioactive waste and to construct and operate a repository, if such a repository was approved under the NWPA. Moreover, if public liability arose out of nuclear waste activities funded by the Nuclear Waste Fund subject to a DOE agreement of indemnification, compensation must be paid from that fund up to the maximum amount of protection. The Fund, established by the NWPA, pays for DOE activities involved with the proposed repository.

M.8.9 STATE, NATIVE AMERICAN, AND LOCAL GOVERNMENT PERSONS WHO ARE INDEMNIFIED

State, Native American, and local governments are included among the "persons" who may be indemnified if they incur legal liability. A *person* includes "(1) any individual, corporation, partnership, firm, association, trust, estate, public or private institution, group, Government agency other than [DOE or the Nuclear Regulatory] Commission, any state or any political subdivision of, or any political entity within a state, any foreign government or nation or any political subdivision of any such government or nation, or other entity; and (2) any legal successor, representative, agent, or agency of the foregoing" (42 U.S.C. 2214). A state or a political subdivision of a state may be entitled to be indemnified for legal liability, including all reasonable additional costs incurred in the course of responding to a nuclear incident or an authorized precautionary evacuation. In addition, indemnified persons could include contractors, subcontractors, suppliers, shippers, transporters, emergency response workers, health professional personnel, workers, and victims.

M.8.10 PROCEDURES FOR CLAIMS AND LITIGATION

Numerous provisions ensure the prompt availability and equitable distribution of compensation, including emergency assistance payments, consolidation and prioritization of claims in one Federal court, channeling of liability to one source of funds, and waiver of certain defenses in the event of a large accident. The Price-Anderson Act authorizes payments for the purpose of providing immediate assistance following a nuclear incident. In addition, it provides for the establishment of coordinated procedures for the prompt handling, investigation, and settlement of claims resulting from a nuclear incident.

M.8.11 FEDERAL JURISDICTION OVER CLAIMS

The U.S. District Court for the district in which a nuclear incident occurs shall have original jurisdiction "with respect to any [suit asserting] public liability...without regard to the citizenship of any party or the amount in controversy" [42 U.S.C. 2210(n)]. If a case is brought in another court, it must be removed to the U.S. District Court with jurisdiction upon motion of a defendant, the Nuclear Regulatory Commission, or DOE.

M.8.12 CHANNELING LIABILITY TO ONE SOURCE OF FUNDS

The Price-Anderson Act channels the indemnification (that is, the payment of all claims arising from the legal liability of any person for a nuclear incident) to one source of funds. This "economic channeling" eliminates the need to sue all potential defendants or to allocate legal liability among multiple potential defendants. Economic channeling results from the broad definition of "persons indemnified" to include any person who may be legally liable for a nuclear incident. Thus, regardless of who is found legally liable for a nuclear incident resulting from a DOE contractual activity or Nuclear Regulatory Commission-licensed activity, the indemnity will pay the claim.

In the hearings on the original Act, "the question of protecting the public was raised where some unusual incident, such as negligence in maintaining an airplane motor, should cause an airplane to crash into a reactor and thereby cause damage to the public. Under this bill, the public is protected and the airplane company can also take advantage of the indemnification and other proceedings" (DIRS 155789-DOE 1999, p.12).

M.8.13 STATE TORT LAW ESTABLISHES LEGAL LIABILITY

Legal liability is not defined in the Price-Anderson Act, but the legislative history indicates clearly that state tort law determines what legal liabilities are covered (DIRS 155789-DOE 1999, p. A-6). In 1988, "public liability action" was defined to explicitly state that "the substantive rules for decision in such action shall be derived from the law of the state in which the nuclear incident involved occurs, unless such law is inconsistent with the provisions of [Section 2210 of Title 42]" (42 U.S.C. 2014).

M.8.14 PROVISIONS WHERE STATE TORT LAW MAY BE WAIVED

The Price-Anderson Act includes provisions to minimize protracted litigation and to eliminate the need to prove the fault of or to allocate legal liability among various potential defendants. Certain provisions of state law may be superseded by uniform rules prescribed by the Act, such as the limitation on the awarding of punitive damages. In the case of an extraordinary nuclear occurrence (that is, any nuclear incident that causes substantial offsite damage), the Act imposes strict liability by requiring the waiver of any defenses related to conduct of the claimant or fault of any person indemnified. Such waivers would result, in effect, in strict liability, the elimination of charitable and governmental immunities, and the substitution of a 3-year discovery rule in place of statutes of limitations that would normally bar all suits after a specified number of years.

M.8.15 COVERAGE AVAILABLE FOR ACCIDENTS IF THE PRICE-ANDERSON ACT DOES NOT APPLY

If an accident does not involve the actual release of radioactive materials or a precautionary evacuation is not authorized, Price-Anderson indemnification does not apply. If the Price-Anderson Act indemnification does not apply, liability is determined under state law, as it would be for any other type of transportation accident. Private insurance could apply. As noted above, however, all DOE contracts for transportation of spent nuclear fuel and high-level radioactive waste to a repository would be covered by the Price-Anderson Act for nuclear incidents and precautionary evacuation. Persons indemnified under that DOE contractual activity would include the contractors, subcontractors, suppliers, state, Native American, and local governments, shippers and transporters, emergency response workers and all other workers and victims.

Carriers may have private insurance to cover liability from a non-nuclear incident and for environmental restoration for such incidents. All motor vehicles carrying spent nuclear fuel or high-level radioactive waste are required by the Motor Carrier Act, (42 U.S.C. 10927), and implementing regulations (49 CFR Part 387), to maintain financial responsibility of at least $5 million. Federal law does not require rail, barge, or air carriers of radioactive materials to maintain liability coverage, although these carriers often voluntarily cover such insurance. Private insurance policies often exclude coverage of nuclear accidents. Thus, private insurance policies only apply to the extent that Price-Anderson is not applicable.

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Appendix N

Are Fear and Stigmatization Likely, and How Do They Matter

Robert E. O'Connor studies the origins and consequences of risk perceptions. In the past 4 years his work has appeared in *Risk Analysis, Journal of Risk Research, Risk — Health, Safety, & Environment, Risk Decision and Policy, Public Understanding of Science, Social Science Quarterly, and American Journal of Political Science.* The U.S. Environmental Protection Agency is funding his present research on the development and application of ecological and socioeconomic indicators for integrated assessment of aquatic ecosystems of the Atlantic Slope in the Mid-Atlantic States.

O'Connor earned his doctorate in political science from the University of North Carolina and his undergraduate degree from Johns Hopkins University. Currently on leave from the Political Science Department at Pennsylvania State University, Dr. O'Connor is directing the Decision, Risk, and Management Sciences Program at the National Science Foundation.

ARE FEAR AND STIGMATIZATION LIKELY, AND HOW DO THEY MATTER

Lessons from Research on the Likelihood of Adverse Socioeconomic Impacts from Public Perceptions of the Proposed Yucca Mountain Repository

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Are Fear and Stigmatization Likely, and How Do They Matter?

Lessons from Research on the Likelihood of Adverse Socioeconomic Impacts from Public Perceptions of the Yucca Mountain Repository

Executive Summary

The report summarizes the research on perception-based impacts and stigma effects and uses this research to assess qualitatively the likelihood that perceptions of danger and of stigma, regardless of whether they are based on accurate scientific assessments, might result in adverse socioeconomic impacts on Nevada, particularly the Las Vegas area.

There is a consensus among social scientists that a quantitative assessment of the potential impacts from risk perceptions of the repository and the transportation of spent nuclear fuel and high-level radioactive waste is impossible at this time and probably unlikely even after extensive additional research. The implication is not that impacts would probably be large, but simply difficult to quantify. Social scientists do not know enough to identify what would be the level of concern during the operation of a repository. Similarly, we cannot specify the links between those attitudes and individual decisions that would have socioeconomic impacts. Based upon what we do know from surveys and from analogues, we can assess qualitatively what outcomes seem most likely.

Effects from Perceptions of the Proposed Repository
In the absence of a large accident at the repository or a continuing series of smaller accidents, there is little reason to expect adverse effects:

- Although, when asked, many people report that they think of nuclear things as dangerous, these attitudes are usually not salient in people's lives and therefore do not influence personal decisions.
- Yucca Mountain is 90 miles from Las Vegas.
- Studies show few indications of adverse socioeconomic effects (and many positive socioeconomic effects) in places that currently safely store or dispose of radioactive waste.
- People who choose to vacation in Las Vegas are less likely to be concerned about the repository than people who choose to vacation elsewhere. Opening a repository, if there is any impact, would likely reinforce the preferences of people who do not intend to visit Las Vegas with or without an operating repository 90 miles away. People who like to visit Las Vegas would likely pay little attention.
- If the repository would be such a powerful disincentive to investors, businesses considering relocating to southern Nevada, and retirees and others considering relocating in the area, some effects of those perceptions should already be apparent. It is widely known that Congress has ordered DOE to characterize Yucca Mountain for consideration for a repository and that key program documents suggest that the site may be acceptable. If the proposed repository is such a powerful disincentive, prudent investors, facing a possible opening of the repository, would not

> be investing in southern Nevada. Similarly, we would see a decline in population in southern Nevada as businesses and people decide to settle elsewhere in anticipation of future risks and stigma. There is no evidence of this behavior. Indeed, the opposite is true.

The assessment that substantial adverse socioeconomic impacts from perceptions of the repository are quite unlikely assumes that operations at the facility will not have either a major accident (e.g., an explosion with a significant release of ionizing radiation bringing about exposures downwind, some cases of radiation poisoning, and deaths) or periodic smaller accidents (e.g., damaged canisters with some releases of ionizing radiation). These events would most likely raise fears about the repository, make the repository salient to people in southern Nevada, result in some social amplification of risk, and perhaps even stigmatize the region. Adverse socioeconomic effects from perceptions of an accident-prone repository might be substantial even with the repository 90 miles away. Without nuclear accidents at Yucca Mountain, these effects are quite unlikely.

Effects from Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste
Absent accidents, there is no reason to expect impacts for property owners in areas beyond the transportation corridors. Even absent accidents, however, two studies report that, at least temporarily, a decline in residential property values of approximately 3 percent may be expected in transportation corridors in urban areas. Data from other transportation experiences (e.g., transuranic waste to WIPP) suggest that impacts on property values might be negligible or nonexistent. More research on whether property values have fluctuated with the transportation of radioactive materials would be beneficial, although the research would not allow analysts to know with certainty whether there would be any impacts from perceptions of shipments of spent nuclear fuel and high-level radioactive waste to a Yucca Mountain Repository, or how long such impacts would persist.

Are Fear and Stigmatization Likely, and How Do They Matter?

Lessons from Research on the Likelihood of Adverse Socioeconomic Impacts from Public Perceptions of the Proposed Yucca Mountain Repository

1.0 Introduction

1.1 Background

In 1982, Congress passed the Nuclear Waste Policy Act (NWPA) to provide a framework for managing the nation's spent nuclear fuel and high-level radioactive waste. In 1987, Congress significantly amended the Act. These amendments directed the Secretary of Energy to study only Yucca Mountain as the site for a potential monitored geologic repository and, after completion of the studies, to recommend whether the President should approve the site for development as a repository. In response to the Act, the U.S. Department of Energy (DOE) has maintained a program of investigations and evaluations to assess the suitability of the Yucca Mountain site as a geologic repository, and to provide information for the environmental impact statement (EIS) required by the NWPA to accompany any approval recommendation.

The National Environmental Policy Act of 1969 (NEPA) process for the Yucca Mountain site has included meetings with the public to scope what DOE should include in the EIS and, subsequently, the publication of the *Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (U.S. Department of Energy 1999) (Draft EIS) in July 1999 and the *Supplement to the Draft Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada* (U.S. Department of Energy 2001) (Supplement) in May 2001. Many comments on the Draft EIS and the Supplement, including several from the State of Nevada, contend that DOE would strengthen the EIS by giving attention to the possible impacts of perceptions associated with the proposed repository and the transportation of spent nuclear fuel and high-level radioactive waste.

Several different individuals and organizations have examined the potential socioeconomic impact of perceptions. DOE sponsored some of this research itself. In addition, DOE has made funding available to the State of Nevada and to county governments in southern Nevada to hire experts to evaluate the DOE-funded research as well as to conduct their own studies. As a result, there is a substantial body of literature that has explored possible socioeconomic impacts of perceptions about the proposed repository and transportation of spent nuclear fuel and high-level radioactive waste to such a repository.

Early in the site evaluation process for Yucca Mountain, the State of Nevada suggested a potential for perception-based impacts to cause adverse effects to the socioeconomic environment of the State of Nevada. The State's concern was:

- If many people perceive significant risks to themselves associated with the transportation and disposal of spent nuclear fuel and high-level radioactive waste, and
- If those risk perceptions then influence individual behavioral decisions, then

- Nevada, and particularly the Las Vegas area, will become a less attractive location for vacations, relocation of individuals and families, and business investments and relocations.

The concern, at its most extreme, is that perceptions of the Las Vegas area as a dangerous place could bring about a mass stigmatization of the Las Vegas area as a place that people should avoid. This mass stigmatization could then lead to a collapse of the tax base of southern Nevada.

In 1986, the State of Nevada initiated research on these “special effects” to “... devise methods for characterizing and estimating the potential for this unique class of impacts” (Loux 2000, 4). Since 1986 the State of Nevada and, more recently, some of the counties and cities in southern Nevada have commissioned studies that have explored the potential impact of risk perceptions.

During the same period, the DOE kept abreast of the research reported by the State of Nevada and sponsored its own research efforts, primarily through Argonne National Laboratory. These efforts resulted in an annotated bibliography (Nieves et al., 1990) of the literature regarding socioeconomic impacts associated with perceived risks, as well as several research reports and articles prepared by scientists at Argonne National Laboratory.

In the mid-1990s two summaries of what social scientists knew at that time about the potential impacts of risk perceptions appeared. Both projects were independent of DOE.

- In 1995 the Nuclear Waste Technical Review Board (NWTRB) produced one of the summaries, drawing upon NWTRB staff resources as well as the results of a 2-day meeting with ten social scientists who had researched risk perceptions related to radioactive materials. The NWTRB, which Congress established in the NWPA to evaluate the technical and scientific validity of site characterization activities, wanted to develop a better understanding of the relevant issues and questions and to ascertain if they adequately could be addressed and assessed in the context of the potential repository at Yucca Mountain (NWTRB 1995b, 6-7).

- In 1997, Doug Easterling, who had participated in a number of the State of Nevada's research efforts, produced the second summary of the potential impacts of risk perceptions. He published in *Risk Analysis* a review of studies produced by the State of Nevada and others.

The NWTRB and Easterling reviews established a baseline, as of 1997, of the available research in the field of perception-based impacts and stigma effects. This report will draw upon their findings as well as the results from more recent work.

During the scoping process for the Draft EIS, DOE received comments on the need to address perception-based impacts and stigma effects in the EIS. Guided by the conclusions reached by the NWTRB summary and the Easterling article, and by its own research, DOE decided at that time that, while the possibility of such negative impacts cannot be dismissed as entirely impossible, the state of the science was not sufficiently advanced to anticipate and measure the occurrence or extent of such impacts with any reasonable degree of accuracy. Therefore, results of these types of analyses would be so uncertain or speculative that they would not provide any meaningful input for decision-makers.

Because of the nature of the comments received on the Draft EIS and the Supplement to the Draft EIS, DOE has elected to reexamine the relevant literature and assess the state of the research into perception-based impacts and stigma effects.

1.2 Purpose

The purpose of this paper is to summarize the research on perception-based impacts and stigma effects and to use this research to assess qualitatively the likelihood that perceptions of danger and of stigma, regardless of whether they are based on accurate scientific assessments, could result in adverse socioeconomic impacts on Nevada, particularly the Las Vegas area.

1.3 Data

This report does not involve the collection of new data gathered specifically for this effort. The author reviewed the available literature, including work supported by DOE, the State of Nevada, and others.

1.4 Scope and Organization

After the introductory section, Section 2 describes the research literature related to possible effects from perceptions. The section reviews two documents that summarize findings (the 1995 NWTRB report and the 1997 Easterling article) and significant research published since those summary works.

Then, Section 3 assesses the ability of social scientists to estimate the likelihood, based upon the literature, that people in Nevada would feel threatened by the repository if it is constructed and operated at Yucca Mountain. Also, the section assesses possible risks related to transportation of spent nuclear fuel and high-level radioactive waste along transportation corridors. Do social scientists know enough to estimate risk perception impacts with a high level of certainty? Based upon what we do know, what levels of risk perceptions seem most likely?

Section 4 assesses the likelihood that people who view the repository as risky and who say they would feel threatened would actually change their behavior because of fears of the repository. This is the link between expressed attitudes and behavior. Are social scientists certain that current expressed attitudes are good predictors of future behavior? In summary, can social scientists estimate with a high degree of confidence the impacts of the repository on risk perceptions, behavior, and the Nevada economy in general as well as on selected sectors such as tourism and gaming? Based upon what we do know, are significant impacts from perceptions likely?

Next, Section 5 assesses the likelihood of stigmatization of the region as a result of the repository and transportation of spent nuclear fuel and high-level radioactive waste, again using the NWTRB and Easterling work as baseline scholarship as well as drawing on more recent work. Do social scientists know enough to estimate the probability of stigmatization with a high level of certainty? Are people who are likely to stigmatize the region also likely to act upon their views? Based upon what we do know, is stigmatization likely? If stigmatization happens, will individuals change their behavior? What will be the most likely impacts on the economy as a whole, on particular sectors, and on property values along transportation routes? Based upon what we do know, are significant impacts likely?

Finally, Section 6 describes what the state-of-the-art of perception-based impacts allows us to conclude about these impacts and with what degree of certainty. Is quantitative risk assessment possible? What can we conclude about the likely impacts of perceptions about the repository program?

2.0 The Research Literature

2.1 Summaries Published in 1995 and 1997

This section first reports the findings from two documents, a 1995 NWTRB report and a 1997 article by Doug Easterling, that were not directly supported by funding from DOE. The authors of these documents sought to summarize what social scientists know about the possible effects of perceptions about the proposed repository and the shipment of spent nuclear fuel and high-level radioactive waste in the future. Then, the section reviews selected studies written since those summaries.

NWTRB Report to the U.S. Congress and the Secretary of Energy

On May 23 and 24, 1995, the NWTRB held a “Joint Meeting of the Panels on Risk and Performance Analysis and the Environment and Public Health” to discuss “Perceptions of Risk and Social and Economic Impacts” (NWTRB 1995b). Ten distinguished social scientists (Gilbert Bassett, Doug Easterling, Hank Jenkins-Smith, Stephen Kraus, Warner North, James Opaluch, Howard Schuman, Paul Slovic, Elaine Vaughan, and Lee Wilkins) examined the link between risk perception and socioeconomic impacts. These scholars represented a diverse range of social science disciplines and experience including economics, journalism, political science, psychology, sociology, and survey research. Some had received funding directly from DOE, some from the State of Nevada, and some from neither organization. The NWTRB sought to “ventilate the methodological, empirical, and analytic issues, the technical questions that would have to be addressed to reach a grounded and sound conclusion on the validity of the proposition” (NWTRB 1995b, 7) that “perceptions of risk associated with a repository lead to significant adverse social and economic effects” (NWTRB 1995b, 6).

Garry Brewer, chairperson of the NWTRB panels on Risk and Performance Analysis and the Environment and Public Health, ran the sessions that contributed to the NWTRB’s annual *Report to the U.S. Congress and the Secretary of Energy* (NWTRB 1995a). He asked the social scientists to comment on the sequence that must occur in order for perceptions to lead to impacts that can be identified and mitigated or avoided. Brewer posited that, “ ... the chain … begins with risk and risk perception, and works its way through behavior, and from behavior to impact, and from impact, in social and economic terms, to mitigation and compensation” (NWTRB 1995a, 3). The *Report* concluded:

- “What are the origins of risk perceptions?

  There is a strong understanding of what factors (attitudinal, demographic, cultural, knowledge) influence risk perceptions. Very little consensus has emerged about the relative importance of those factors” (NWTRB 1995a, 43).

- “What is the link between attitudes and behaviors?

  There appears to be only a modest link between attitudes, such as risk perceptions, and consequent behaviors” (NWTRB 1995a, 43). At the meeting, Brewer summarized, “ ... it's very, very difficult, tenuous, risky, absent a real sensitive understanding of context, to go from one's best measured sense of risk perception to predicting behavior” (NWTRB 1995b, 64). Stephen Kraus agreed, “The bottom line is I came up with 80 or 90 studies that seemed to be good, fairly methodologically sound tests of this question, of do attitudes predict behavior, and the answer seems to be a definitive, sometimes” (NWTRB 1995b, 89).

- “How do individual behaviors translate into socioeconomic impacts?

> The relationship between individual behaviors and socioeconomic impacts has almost exclusively been inferred from anecdotal or case study evidence. Should another anecdote or case suggest a contradictory conclusion, no basis currently exists for distinguishing among different interpretations.... Moreover, other environmental, economic, and social conditions or trends could influence the socioeconomic well-being of southern Nevada, making isolating the impacts associated with a future repository very difficult" (NWTRB 1995a, 43).

- "How are impacts evaluated? How can they be compensated for or mitigated?

  At the core of the compensation and mitigation issue are three questions: How do you know if some response is needed, especially for a project that will be implemented over the next century? How can any harm experienced be quantified in monetary terms? Are there certain types of harm that intrinsically cannot be compensated for or mitigated against either because of their nature or their magnitude? The social sciences have not yet provided very determinative answers to those questions" (NWTRB 1995a, 43).

The NWTRB concluded that, "Standard socioeconomic impacts have been analyzed in a variety of contexts using relatively standard methodologies.... Special socioeconomic effects, caused by perceptions of risk, are much more difficult to predict. Substantial theoretical, methodological, and conceptual obstacles need to be overcome before much confidence can be given to predictions of more than a few years" (NWTRB 1995a, 44).

Doug Easterling, "The Vulnerability of the Nevada Visitor Economy to a Repository at Yucca Mountain"

In 1997 *Risk Analysis* published Easterling's review of the "… studies commissioned by the Nevada Nuclear Waste Project Office to estimate the economic impact of a high-level nuclear waste repository at Yucca Mountain" (Easterling 1997, 635). The purpose of his article was to review the:

> "… socioeconomic research program undertaken by the NWPO [Nevada Nuclear Waste Project Office], outlining the research questions, methods, and findings from a variety of studies that examine the potential for visitor impacts. In general, these studies explore the question of whether a repository at Yucca Mountain would influence the decision to visit Nevada for a vacation, meeting, or convention.… Three distinct methodologies have been used to investigate visitor impacts: case studies, elicitation of behavioral intent, and theory testing…. The primary purpose of this paper is to describe what is known and what is not known and to help establish an agenda for future socioeconomic studies" (Easterling 1997, 636).

In addition to studies supported by the State of Nevada, the review recognized research commissioned by DOE, as well as research not sponsored by stakeholders.

Easterling describes the research commissioned by the State of Nevada as focused on three theories of visitor impact: risk-avoidance, negative imagery, and stigmatization. The "risk-avoidance" model is based on the standard theories of self-protective behavior; i.e., "… people avoid destinations they perceive to be risky" (Easterling 1997, 637). This model suggests that Nevada could suffer economic losses "… if potential visitors view the repository as a major hazard" (Easterling 1997, 637). Furthermore, the risk-avoidance theory suggests that "... the potential for economic losses increases if the repository is plagued by mishaps or mismanagement" and the effects might be compounded "... if repository-related concerns are highlighted by the media or interest groups" (Easterling 1997, 637). Regarding the construct of "negative imagery," Easterling states that researchers have assumed that the repository will work its way into the "image set" of places in the vicinity. "In other words, when people think of the prospect of visiting Las Vegas, the repository will become one of the images that comes to mind. The theory assumes that this image will be highly aversive for the typical individual, and as such, will reduce the decision-maker's preference for visiting Las Vegas" (Easterling 1997, 637). Easterling points out that the risk-avoidance and negative-imagery models represent independent and complementary pathways to influence visitor decisions. That is, the negative imagery model suggests that visitors might avoid any place they feel has an unpleasant or noxious image, regardless of whether they perceive that location to be risky. The risk-avoidance and negative-imagery models both suggest that impacts on visitor decisions would be exacerbated by serious repository-related accidents with extensive coverage by the media.

The third theory, "stigmatization" is characterized as "... the extreme case of either the risk-avoidance or negative-imagery process" (Easterling 1997, 638). Easterling notes that "Stigmatization is likely to require a rather extreme initiating event" such as a "... radiation release as extreme as the Chernobyl accident ... but stigmatization is less likely under more benign scenarios" (Easterling 1997, 638). However, "... even if stigmatization does not occur, the repository could marginally increase the perceived risk and/or imagery associated with the state, which might still impact visitor behavior" (Easterling 1997, 638).

In his review of the historic research, Easterling summarizes both the "Nevada studies" and the "counter-evidence studies" and indicates that the research commissioned by the State of Nevada "... suggests that there are instances in which nuclear facilities have led to losses in the visitor economy of nearby communities" (Easterling 1997, 639), but the counter-evidence studies imply that there is little cause to anticipate visitor impacts. Easterling explains,

> "Some of this contrast stems from a difference in what the researchers were intending to demonstrate. Namely, the Nevada studies specifically sought out cases where economic losses had occurred in order to show that repository-induced impacts were within the range of possibility, whereas Metz [William Metz, Argonne National Laboratory] selected a set of nuclear-weapons facilities that he thought would provide a best-guess estimate of the consequences of a repository" (Easterling 1997, 639).

In other words, the Nevada studies have focused on case studies of accidents that might result in risk avoidance, negative imagery, and/or stigmatization, while the counter-evidence studies have examined the average long-term performance of nuclear facilities. Easterling concludes that the "... primary lesson to draw from the case-study approach is that the impact of a nuclear facility on the local economy depends almost completely on the severity of the events that occur over the lifetime of the facility" (Easterling 1997, 639).

The second element of research examined in the article looks at studies of intended behavior. The State of Nevada sponsored a series of surveys designed to elicit statements of intended behavior from a variety of groups (e.g., the general public, persons who vacation in Nevada, convention planners and attendees). The intent of these studies was to assess possible repository-related effects on respondents' behavior by asking them to "... consider a variety of repository scenarios and indicate how they would behave" (Easterling 1997, 640). These studies invariably found that, based on statements of intended behavior, Nevada would become a less desirable place to visit, start a business, relocate, invest, etc. As Easterling observes, however, "Still, one must acknowledge that the link between stated intent and subsequent behavior is far from perfect" (Easterling 1997, 642). The long period between conducting the survey and opening the repository increases disparities between stated intentions and actual behavior.

Finally, the article turned to the third component of the research commissioned by the State of Nevada: studies to understand visitation decisions. The intent of this research was to test the three theories of visitor impact—risk avoidance, negative imagery, and stigmatization—to the degree possible in the absence of an operating repository. The research examined several propositions associated with these theories:

- Does perceived risk influence behavior?
- Would a repository increase perceived risk for Nevada?
- Does imagery influence visitation decisions?
- Is negative imagery associated with a repository?
- Will repository imagery be aligned with Nevada?

Easterling indicates that the answer to each of these propositions probably is affirmative. There is evidence that suggests risk perceptions influence behavior, perceived risk has remained high for the repository during the period of the studies, imagery does appear to influence visitation decisions, and the imagery associated with a repository largely is negative.

Easterling suggests caution, however, before accepting the proposition that reduced tourism and fewer conventions will occur because of negative imagery from the repository and shipments of spent nuclear fuel. If those individuals who already hold a negative image of Nevada (based on negative attitudes toward legalized gambling, for instance) are also disproportionately the same people who will develop a negative imagery of Nevada because of the repository, "... then we might see only a further alienation of Nevada among the state's detractors, not avoidance among persons who currently visit the state" (Easterling 1997, 645).

Easterling also urges caution regarding the last proposition, that people will necessarily associate the repository with Nevada. Now, when asked about their image of Nevada or Las Vegas, few respondents associate the repository with Nevada, perhaps because the facility has not yet been built. He also notes that the long history of the Nevada Test Site does not appear to be a "... prominent part of the public's mental landscape of Nevada, which calls into question the proposition that people will associate a Yucca Mountain repository with Nevada" (Easterling 1997, 644).

The conclusion of Easterling's review focuses on many of the uncertainties inherent in the studies that he evaluated. He notes that the studies have shown that a "... repository at Yucca Mountain could have a negative impact on Nevada's visitor economy, but this is a possibility rather than an inevitability" (Easterling 1997, 645). He observes that the case studies of analogous facilities have shown that visitors sometimes avoided areas near nuclear facilities, particularly following a well-publicized incident involving radioactive contamination, but those studies do not allow a reliable assessment of when such impacts occur or the magnitude of the impacts. Easterling states, "... the studies of intended behavior provide reason to believe that visitation decisions will be influenced by a repository (at least under severe scenarios), but these studies are subject to substantial imprecision" (Easterling 1997, 645). Regarding the tests of visitor-behavior theories, studies "... support the possibility of a repository leading to avoidance behavior, but uncertainties remain. We know that the perceived risk and imagery associated with a place have an influence on a person's likelihood of visiting that place, but we don't know how a repository at Yucca Mountain will influence the perceived risk and imagery associated with Nevada" (Easterling 1997, 645).

Easterling summarizes his review, "The bottom-line conclusion from these studies is that repository-induced impacts are possible, but uncertain. Furthermore, much of this uncertainty is irreducible" (Easterling 1997, 645). Under a benign scenario, with incident-free operation of the facility and dissipation of controversy, "... the repository would likely have a benign impact on decision-making. On the other hand, if one assumes a severe repository scenario—with a set of high-publicity accidents and controversies—there is a very real potential for significant visitor impacts, in the extreme stigmatizing Nevada as a contaminated place to be avoided. If two researchers make different assumptions about how the repository will perform, they will inevitably arrive at competing economic forecasts" (Easterling 1997, 645).

The conclusions of both independent reviews—the NWTRB Report and the Easterling article—are consistent. The researchers seem in agreement on several points:

- While the body of research, both directly associated with a potential Yucca Mountain repository and unrelated studies, is extensive, significant uncertainties regarding the crucial questions of the effects of public perceptions remain.

- The evidence suggests that there is some understanding of how perceptions are formed, that those perceptions might influence individual behavior, and that those individual behaviors collectively might in some instances lead to socioeconomic impacts. The understanding of those relationships, however, is limited and contextual.

- The repository and transportation of spent nuclear fuel and high-level radioactive waste would not necessarily have either substantial or negative socioeconomic effects from perceptions, although it is possible to conceive of circumstances that would bring about significant negative socioeconomic effects.

- Social scientists have a quite limited capability to measure accurately the occurrence, timing, and extent of socioeconomic effects from future perceptions. There is great uncertainty about (1) the nature and intensity of future perceptions related to the repository and the transportation of spent nuclear fuel and high-level radioactive waste if DOE built the repository, (2) the link of such perceptions to individual behavior, and (3) the link between individual behavior and socioeconomic impacts.

The next sections describe the research since 1997 to report fresh insights and to examine whether the conclusions of 1995 and 1997 require revision.

2.2 Description of Research Since 1997

Most of the research related to risk perceptions published since the Easterling article in 1997 is only tangentially related to the possible socioeconomic impacts of a repository and transportation of spent nuclear fuel and high-level radioactive waste. Much of the research has focused on developing a better understanding of the etiology of perceived risk. Scholars have looked to cultural theory (e.g., Shrader-Frechette 1997; Sj`berg 1998a; Marris, Langford, and O'Riordan 1998; Brenot, Bonnefous, and Marris 1998; Grendstad and Selle 2000; Langford et al. 2000), trust (e.g., Sj`berg and Drottz-Sj`berg 1997; Earle and Cvetkovich 1998; Peters, Covello, and McCallum 1998; O'Connor, Bord, and Fisher 1998; Greenberg and Williams 1999; Slovic 1999; Siegrist 2000; Siegrist and Cvetkovich 2000; Siegrist, Cvetkovich, and Roth 2000; Sj`berg 2001), the role of worry in risk perception (e.g., Sj`berg 1998b; Baron, Hershey, and Kunreuther 2000), and how perceptions of benefits influence risk perceptions (e.g., Slovic 2000; Finucane, et al. 2000). Other research has focused on risk communication (e.g., Long and Fischhoff 2000; Siegrist and Cvetkovich 2001; Chess 2001), the willingness to pay for "zero risk" (e.g., Burger et al. 1997; Nakayachi 1998), and how risky experiences change perceptions (e.g., Rogers 1997).

The authors of five studies published since the Easterling article intended their work to address issues of the socioeconomic effects of perceptions of the proposed repository. This section will review each of those studies in turn.

William Metz and David Clark, "The Effect of Decisions about Spent Nuclear Fuel on Residential Property Values"

In an article funded by DOE and published in the same 1997 issue of *Risk* Analysis as the Easterling article, William Metz and David Clark attempt to determine if property values in the vicinity of two nuclear power plant sites were affected by decisions at the facilities regarding spent nuclear fuel storage and extension of the permit to operate the reactors (Metz and Clark 1997). The data used in the study "... represent individual single-family residential property sales that took place between 1990 and 1994 within 15 miles of the Rancho Seco and Diablo Canyon nuclear plants" (Metz and Clark 1997, 574). The authors report their results: "... decisions and announcements about spent nuclear fuel storage activities have not affected the local residential property market to the extent predicted by surveys of attitudes and images. Our hedonic model results indicate that this finding of no property value effect is the case regardless of whether a plant is operating or closed or whether the high-level waste is to be placed in dry-cask storage facilities immediately or as part of a future action" (Metz and Clark 1997, 581). The authors do note, however, that "... these findings reflect only the current residential property value situation around the two California plant sites; we made no attempt to determine whether there were effects on residential property values at the time of the reactors' siting announcements and construction" (Metz and Clark 1997, 581).

The authors conclude that predictions based on surveys of public perceptions and images might overestimate negative economic effects as reflected in residential property values.

Hank Jenkins-Smith, "Modeling Stigma: An Empirical Analysis of Nuclear Images of Nevada

In 2001 Hank Jenkins-Smith published a chapter in *Risk, Media, and Stigma: Understanding Public Challenges to Modern Science and Technology,* edited by James Flynn, Paul Slovic, and Howard Kunreuther. Funded by DOE, Jenkins-Smith designed and implemented one survey with a national sample and a second survey with a longer questionnaire with residents of Phoenix, Arizona. He wanted to focus "on the processes by which individuals acquire images of different kinds, give value to them, and rely on them in development of preferences" (Jenkins-Smith 2001, 108). He sought to examine a general proposition:

> "… different kinds of individuals are quite likely to acquire and use distinct bundles of images. If this proposition is correct, when new kinds of images (e.g., nuclear ones) are introduced about that place, they are likely to be more readily acquired by some people than others, and once acquired are likely to be valued differently. If so, whether a new image will stigmatize to a place depends on how readily that image is acquired, how it is valued, and how it is attached to preferences for the place by individuals who would otherwise be attracted to that place" (Jenkins-Smith 2001, 108).

The findings of this study are important and worth quoting at length:

- "Some people are more likely to acquire nuclear images of Nevada than others….
- …. the valences attached to images about a place are very strong predictors of vacation preferences for that place. Thus, the more positive the valance of one's images about a place, the more likely it is that one will want to vacation there.
- The valances attached to images of a 'high level nuclear waste repository' appear to be reasonably valid measures of the positive and negative affect that people hold about a nuclear waste repository.

- Despite the implication of some scholars (e.g., Weart 1988) that nuclear imagery is overwhelmingly dread-filled, the valences that people attach to nuclear images of nuclear facilities have considerable variation, ranging from quite positive to quite negative.

- The valences that people attach to nuclear images are related to their cultural and ideological predispositions. Egalitarians and self-described liberals tend to have more negative nuclear image valences, and conservatives and fatalists tend to have more positive ones.

- Nuclear images are part of a broader set of images about Nevada, and the valences of nuclear images are correlated with the valences of other Nevada image categories. Those with more negative valences for nuclear images also tend to have more negative images about gambling, prostitution and entertainment.

- Valences of both nuclear and gambling images appear to be influenced by cultural biases. Egalitarians tend to give more negative valences to both gambling and things nuclear, while fatalists give more positive valences" (Jenkins-Smith 2001, 129).

Jenkins-Smith summarizes,

> "If a new and negative type image is widely introduced into the image sets of a place, the effect of that image on such activities as vacationing, relocating, and retiring will be in part dependent on how the new image is associated with images in the pre-existing image sets. If the new image (e.g., a nuclear image) is negatively associated with the valences of images that previously had served to attract people to the place (e.g., a pristine environment), then the nuclear image is likely to lead to greatest reduction in vacation preferences among precisely those people who used to be most attracted to the place. The wide dispersion of such an image might well result in a stigmatization among those people who used to be attracted to that place. If, on the other hand, the new image (e.g., a nuclear image) is positively associated with the valences of those images that previously had attracted people to the place (e.g., gambling), then the nuclear image will be most positive (or least negative) for those who are most likely to vacation in that place. Those who were least likely to vacation in the place before (those who assigned negative valences to gambling) are the ones for whom the new images will be most negative. In that case, people who didn't want to vacation there before will now want to vacation there even less" (Jenkins-Smith 2001, 130-131).

<u>Louis Berger Group, Inc., Assessment of the Hazards of Transporting Spent Nuclear Fuel and High Level Radioactive Waste to the Proposed Yucca Mountain Repository Using the Proposed Northern Las Vegas Beltway</u>

In 2000 the Louis Berger Group issued a report, *Assessment of the Hazards of Transporting Spent Nuclear Fuel and High Level Radioactive Waste to the Proposed Yucca Mountain Repository Using the Proposed Northern Las Vegas Beltway*, designed to assess quantitatively the economic impacts of high-level nuclear waste transportation. The study commissioned by the City of North Las Vegas states that the transport of spent nuclear fuel and high-level radioactive waste "... along the Northern Beltway could result in significantly lower levels of economic activity and property values in year 2020. These results are based on a comparison between a base forecast of employment and business activity in year 2020 and an assumption that the hazardous waste transport will alter the land use and industry in the study area" (Berger Group 2000, E-3). The assumption used to estimate the economic impacts is that, as a result of the perceived risks and stigma effects associated with radioactive waste transportation, "... no office development will take place in the study area" (Berger Group 2000, 94). The study projects demographic losses in population and related employment; economic losses for reduced sales activities and employment earnings; and losses in property, sales, and state business taxes. The Berger report also asserts that the economic losses in North Las Vegas would result in larger losses in Clark County through a multiplier effect. Such losses would be reflected in reduced sales activities, employment earnings, collections of Nevada State Business Tax, and sales taxes (Berger Group 2000, E-4).

Urban Environmental Research, LLC, Property Value Impacts from the Shipment of High-Level Nuclear Waste through Clark County, Nevada (2000), Clark County Property Value Report on the Effects of DOE's Proposal to Ship High Level Nuclear Waste to a Repository at Yucca Mountain (2001)

In 2000 Urban Environmental Research, LLC (UER) issued a report prepared for the State of Nevada. In 2001 UER expanded the 2000 report by adding a review of the literature on the effects of "adverse environmental conditions" on property values. The purpose of this research by UER was to estimate potential property value effects associated with transporting radioactive waste through Clark County. The design involved interviewing Clark County residents who live near potential transportation routes and a small number of experts involved in lending for real estate investments in southern Nevada. The public survey (subcontracted to the University of Nevada at Las Vegas) asked residents their views on property values, how shipments of radioactive waste might affect these values, and whether residents who did not own property would consider buying near such routes. The other survey asked a small number of professional appraisers and bankers their opinion about how shipments of radioactive waste would influence their behavior and what they estimated would be the effects on property values near routes used for the shipments.

Residents, appraisers, and bankers all expect property values to decline near routes used to transport spent nuclear fuel and high-level radioactive waste. UER concludes, based on the residential survey:

> "Nuclear waste transportation is highly likely to significantly and adversely impact property values at least up to 3 miles from the routes. The reluctance to purchase residential properties near shipment routes by most of the Clark County population will not only result in property values declining but also may adversely effect (sic) the housing industry in the Las Vegas Valley and the level of revenue flow to local governments" (UER 2001, 71).

The conclusion from the survey of appraisers and bankers is that the value of residential properties within one mile of the route might be anticipated to decrease from 2.0 to 3.5 percent while the value of commercial and industrial properties might be anticipated to decline from 0.5 to 3.0 percent. The numbers would be much higher if there were transportation accidents.

These survey findings are typical of those of earlier work that most people say they prefer not to locate near anything nuclear, including transportation routes. The specific UER figures, however, are similar to the findings of the research on actual property values for one of the three counties studied by Gawande and Jenkins-Smith, as noted below.

Gawande and Jenkins-Smith, "Nuclear Waste Transport and Residential Property Values: Estimating the Effects of Perceived Risks"

Rather than depend solely on survey data, Kishore Gawande and Hank Jenkins-Smith collected data on 9,432 real estate transactions in three South Carolina counties to model the effects of a series of highly publicized shipments of spent nuclear fuel to a storage facility at DOE's Savannah River Site. The study, funded by DOE and forthcoming in the *Journal of Environmental Economics and Management*, addressed the question of whether shipments of spent nuclear fuel reduced residential property values. Along with the data of actual real estate sales, Gawande and Jenkins-Smith designed and implemented a survey that showed that many South Carolinians thought that a train accident and the rupture of spent fuel containers was likely. A majority thought that, if an accident occurred, “the nuclear fuel containers would break open and allow radiation to escape” (Gawande and Jenkins-Smith 2001, 7). The conclusions of the study indicate mixed results regarding property values:

> “Our analysis indicates that property values have reacted in different ways to the shipments in the three counties. No declines were evident in predominantly rural Berkeley and Aiken Counties, while an economically and statistically significant decline was evident in more populous Charleston County” (Gawande and Jenkins-Smith 2001, 2).

In Charleston County, “After the shipments began, the net gain in value associated with being five miles away from the route relative to a property on the route was nearly 3% of the average home value” (Gawande and Jenkins-Smith 2001, 22). There were no discernable results in the two more rural counties. Based on the different results for the three counties, the authors urge caution when making generalizations about the effect of spent nuclear fuel shipments on housing values. Gawande and Jenkins-Smith conclude, “Our results, if confirmed in further studies, indicate that there may be important distributional consequences of such shipments that should be considered in policy making. These consequences include suppressed property values when the shipments are highly publicized, controversial, and the focus of claims about extreme risk, as occurred in South Carolina” (Gawande and Jenkins-Smith 2001, 23).

2.3 Conclusions Regarding the Research Conducted Since 1997

The research since the summary article by Doug Easterling in 1997 has not challenged the conclusions he reached. Little new evidence has been developed since 1997 to address the fundamental uncertainties and improve our ability to anticipate accurately the occurrence, timing, or extent of those effects. Significant uncertainties regarding the crucial questions of the effects of public perceptions remain. We do not have a good understanding of the linkages among attitudes, individual behavioral decisions, and socioeconomic impacts. We cannot conclude that negative socioeconomic effects from perceptions regarding a repository and transportation of spent nuclear fuel are likely, although we cannot totally rule out negative effects. Many of the hypotheses involve assumptions that the proposed repository is unique and that tragic accidents would occur at the facility or with transportation. Data are not available to test these hypotheses because the facility is not open. Therefore, although additional research can tantalize and suggest possibilities, it cannot directly address the fundamental uncertainties of possible perceptual effects from the repository and the transportation of spent nuclear fuel and high-level radioactive waste.

Scholars supported by both DOE and the State of Nevada seem in agreement that the limitations and uncertainties noted by Easterling in his review still exist. During the November 1999 public hearing on DOE's water rights applications for the Yucca Mountain Site Characterization Project, James Flynn, formerly the project manager for the State of Nevada's study team, addressed whether Easterling’s claims remain valid. Testifying for the State of Nevada as an “expert in risk, stigmatization and social amplification of risk,” Flynn confirmed that Easterling’s conclusions remain valid: Perception-based impacts and stigma effects associated with the proposed repository at Yucca Mountain are possible but not inevitable, and much of the uncertainty is irreducible (State of Nevada Department of Conservation and Natural Resources 1999, 150, 195-8).

Some of the work since 1997 assumes adverse effects and tries to tally the cost. The Berger Group study (2000) is an example of this type of work. The major limitation of the Berger Group study is that their assumption that no office development would take place near the Northern Beltway begs the question of what would be the impact of the selection of the Northern Beltway as a transportation route. The report assumes that the stigmatization of the Northern Beltway would be so intense that no businesses would be willing to locate near the road. Assumptions are useful only to the degree that they reflect a basis in reality. While the Berger report provides a review of the perception-based impacts literature, the report provides little basis for the assumption that no office development will take place in the study area. Businesses (including business services, health services, communications, financial institutions, and legal, engineering, and management services) that serve a regional market and do not have to locate near a specific client or set of clients have the flexibility to choose a site based on the desire to avoid a stigmatized transportation artery. Still, there is no evidence in the literature that businesses would consider only the assumed stigma in making business office location decisions

The second problem with the Berger report is its overstatement of losses even if there were no new development in the transportation corridor. The study's baseline projections for 2010 and 2020 are based on land use master plans for the Northern Beltway area (Berger Group, Inc. 2000, 67) and a reasonable assumption that the types and mix of businesses attracted to the Northern Beltway area will be similar to those located near the recently completed Southern Beltway (Berger Group 2000, 75-76). While not explicitly stated in the report, some portion of the growth in the Northern Beltway area must be due to relocation of people and businesses from other parts of Clark County. This conclusion emerges from three lines of reason.

First, some of the people who will move to the Northern Beltway area are certain to come from elsewhere in Clark County. The Berger report projects a population increase of approximately 138,000 persons living within 2 miles of the Northern Beltway from 2010 to 2020 (Berger Group 2000, Tables 7-2 and 7-3). During the same period, Clark County and the University of Nevada, Las Vegas projects a total county population increase of approximately 331,000 (Riddel and Schwer 2000, p. 3). The Berger projected population increase along the 13-mile sector of the Northern Beltway is approximately 42 percent of the total projected population increase in the county. An increase in population for such a small area that contains such a large portion of the total increase in the county population does not appear to be reasonable unless it includes substantial relocation from other areas of Clark County.

Second, some of the new businesses along the Northern Beltway are certain to come from elsewhere in Clark County. Table 7-9 of the Berger Group report shows that many businesses in the Southern Beltway area had relocated from elsewhere in Clark County. There is no reason to assume that the same relocation activity pattern will not occur along the Northern Beltway. Such an activity is consistent with business location decisions to take advantage of new infrastructure.

A third reason for the overestimation of losses, even given the assumption that no firms would locate near the Northern Beltway, is that the report's conclusions require that businesses that decide not to locate near the Northern Beltway also not locate elsewhere in Clark County. The analysis and identification of losses (such as reduced tax revenues) are dependent on the assumption that businesses do not locate anywhere in the region where they would pay such taxes. Even if stigmatization of the transportation routes were to occur, businesses would still locate in Clark County. In such an instance, stigmatization would come into play only in terms of the selection of the specific site within the region.

In summary, the Berger Group report takes a worst-case assumption regarding stigma effects, an assumption not supported by any transportation-related stigma event in history. Within this scenario the report then overestimates negative impacts by ignoring the in-county nature of many individual and business location decisions.

The UER work also has limitations, although they are quite different from those of the Berger Group study. The major problem of the UER survey is with accepting the stated intentions as good predictors of behavior (and lower property values). One reason to expect a large attitude/behavior gap is the several years between the survey response and the actual transportation of radioactive waste if the repository were to be built. The longer the time between expressing an attitude and having the opportunity to act upon it, the weaker is the predictive capability of the attitude. Finally, although there are no systematic studies of the effects on transporting radioactive waste on residential property values (with the exception of the 2001 Gawande and Jenkins-Smith study), there is much evidence of high property values near nuclear facilities (see, for example, Metz, 1994). It is not obvious why Nevadans would act differently.

Social science research on perception effects has had some important advances since 1997. Jenkins-Smith (2001) has made an impressive start toward elaborating the stigma model developed initially by Slovic et al. (1991). Jenkins-Smith shows that a repository and shipments of radioactive waste are less likely to bring negative socioeconomic effects through stigma than the earlier model had suggested. The people most likely to stigmatize Las Vegas because of its proximity to Yucca Mountain are the same people who already stigmatize Las Vegas for other reasons. They have no intention of relocating to southern Nevada with or without the repository. Still, more research on how different people make risk perceptions salient is needed.

Another advance is the work of Gawande and Jenkins-Smith (2001), the first systematic study of impacts on property values from the transportation of spent nuclear fuel. Highly publicized shipments of foreign spent nuclear fuel apparently did depress housing prices near the train tracks in an urban county, but had no effect in two rural counties. This is an important case study that calls for replication in other communities where DOE transports spent nuclear fuel, and for validation of the duration of the depression on housing prices. The policy implications for compensation and mitigation could be significant, particularly if the depression was of long-lasting effect.

The work of Metz and Clark (1997) also contributed to a better understanding of effects related to perception-based impacts by studying actual cases. Their study and the Gawande and Jenkins-Smith article (2001) indicate that economic impacts in the form of effects on property values can occur in some, but by no means all, situations.

3.0 Risk Perceptions of the Repository and Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste

This section is a qualitative assessment, based upon the literature discussed above as well as studies cited only in this section, of the likelihood that people would feel threatened in Nevada, and particularly the Las Vegas area, by the repository and transportation of spent nuclear fuel and high-level radioactive waste through southern Nevada.

In assessing the likelihood that Nevadans would feel threatened by the repository or the transportation of spent nuclear fuel and high-level radioactive waste, a number of observations are relevant:

- **Although a large proportion of people, when asked, report negative images of nuclear facilities and say they are risky, there is only weak and problematic evidence that people would feel threatened by a radioactive waste repository 90 miles away.**

One problem with testing hypotheses regarding whether people would be fearful of vacationing or living 90 miles away from a high-level radioactive waste repository is that there is no such repository anywhere that would allow social scientists to gather data to test perceptual hypotheses. The best we can do is to ask people to imagine how they might feel and to reason from analogies.

When social scientists ask people what they think of a radioactive-waste disposal facility, many report negative images related to risk (e.g., Slovic et al. 1991). This finding is by no means the same as a finding that many people would feel threatened by the repository if it were to open. There are two criteria that must be met before people would feel threatened by the repository. First, the Yucca Mountain Repository would have to become salient so that people would accept information about it and care about that information. Second, the information about the repository would have to engender beliefs that the repository threatens them.

Regarding the salience criterion, Yucca Mountain seems likely to become salient to neither Nevadans nor potential vacationers. The Nevada Test Site has not been and is not now a salient part of the way most people think about southern Nevada. The proposed repository is not, despite extensive press coverage in Nevada and across the nation, part of the way most people think about southern Nevada. It is unclear why the operation of the proposed repository would necessarily make the repository salient to the people of Nevada and to potential vacationers.

Even if the repository becomes salient, survey data show that not everyone will necessarily become fearful of adverse effects from a facility that is 90 miles away (Jenkins-Smith, 2001). Analogues also show that nuclear facilities are by no means necessarily disincentives to investors or to businesses and people considering relocation to the area. The closest analogues we have to the proposed repository are low-level waste facilities, Federal nuclear reservations (e.g., Hanford), the Waste Isolation Pilot Project (WIPP), and nuclear power plants. Communities are thriving well within 90 miles of these facilities. Similarly, there is little evidence that these facilities have frightened actual or potential tourists. Disneyland is 35 miles from San Onofre, which has at-reactor storage of spent nuclear fuel. There is no evidence that this situation has either frightened tourists or deterred them from visiting Anaheim.

Unless there is a major accident (e.g., an explosion with a significant release of ionizing radiation bringing about exposures downwind, some cases of radiation poisoning, and deaths) or periodic smaller accidents (e.g., damaged canisters with some releases of ionizing radiation), there is little reason to expect a repository to be salient to more than a small minority of southern Nevada residents and visitors. Many people might continue to say that a repository is risky when asked, but a repository will not be a salient part of their thinking and they will not feel threatened.

- **Different people react to information about nuclear facilities differently. The people who visit Las Vegas now are disproportionately less likely to attend to information about the repository and be concerned than are people who choose to vacation elsewhere.**

The Jenkins-Smith study (2001) shows that not everyone is equally disposed to fear a repository. Las Vegas vacationers are disproportionately predisposed neither to attend to information about the repository nor to feel threatened by radioactive waste. The implication of this finding is that the tourist industry of southern Nevada is less vulnerable to adverse socioeconomic impacts from a radioactive waste repository than other places would be.

- **Although a large proportion of people, when asked, report negative images of shipments of spent nuclear fuel and high-level radioactive waste, it is not clear that a substantial number of people would feel threatened by such shipments.**

Social scientists have devoted less energy to studying perceptions regarding the transportation of spent nuclear fuel and high-level radioactive waste than regarding the proposed repository. Nevertheless, both Flynn et al. (1997) and Gawande and Jenkins-Smith (2001) provide strong evidence that people think a transportation accident both is likely to happen and, if there was an accident, likely to bring harm to the people who live near the location of the accident. These attitudes suggest a possibility that many people along transportation routes might feel threatened by the shipments, but this scenario is not inevitable. As with threatening feelings about a repository, there are two criteria that must be met to turn questionnaire responses that shipments of spent nuclear fuel and high-level radioactive waste are risky into perceptions that those shipments are threatening. First, the situation with routes and shipments would have to become salient so that people would attend to information about it and care about that information. Second, the information about the shipments would have to engender beliefs that the shipments are threatening.

Regarding the salience criterion, why transportation of spent nuclear fuel and high-level radioactive waste would necessarily become salient is not obvious. In the past 40 years, over 2,500 shipments of spent nuclear fuel have taken place around the country, most with little attention. Publicized disputes have occurred related to some shipments of radioactive waste, specifically those involving transuranic waste to the WIPP and foreign spent nuclear fuel. These shipments are probably the closest analogues to the Nevada situation. In the WIPP situation, incident-free shipments seem to have minimized both the salience and threat perceptions related to transportation of transuranic waste among residents along corridors (Thrower, Portner, and Holm, 2001). In the case of foreign spent nuclear fuel shipped to the Savannah River site, as noted in Section 2.2, there is evidence that many residents in the Charleston area of South Carolina did feel threatened by the shipments.

One interpretation of the data regarding transportation of radioactive waste draws heavily on the Charleston area study (Gawande and Jenkins-Smith, 2001). This understanding of risk perceptions regarding transportation is that, early in the operation of the repository, transportation could be salient to many residents who could also feel threatened. With incident-free shipments, over time these residents along transportation corridors can be expected to forget about the issue. A second interpretation of the data gives more weight to the ongoing experience of frequent shipments around the country with little public concern and views the Charleston area case study as an aberration. This second understanding of risk perceptions regarding transportation is that few people along the routes are likely to notice or to care.

4.0 Linking Risk Perceptions to Behavior

This section reviews the literature linking risk perceptions to behavior, with particular attention to assessing whether attitudes about the repository and the transportation of spent nuclear fuel and high-level radioactive waste are likely to influence individual decisions.

- **Attitudes are usually poor predictors of behavior.**

Sidney Kraus (1995) published a meta-analysis of studies relating attitudes to behavior. He concluded that, at best, attitudes only sometimes strongly relate to behavior. Attitudes are good predictors of behavior only when a number of specific criteria are realized. These criteria include great specificity of the attitude and behavior, a short time between the solicitation of the attitude and the behavior, and the high potency of the attitude.

“Which presidential candidate are you going to vote for in tomorrow’s election?” will predict well; “Are you likely to move if, 4 years from now, the government puts in a hazardous-waste incinerator in the town?” is not a good predictor. The second question involves a considerable gap in time between the elicitation of the attitude and the decision. Also, voting is a low-cost decision whereas whether to move is more difficult.

High potency means that the attitude is strong and important to the respondent because of how it was acquired. Two people might give similar negative responses to questions about Health Maintenance Organizations (HMOs). One person reached that view because of comments from friends and late-night television comedians. The other person arrived at that same attitude because of numerous personal negative experiences with an HMO. The latter is much more likely to take action.

Questions that elicit attitudes that are socially desirable often fail to measure the attitude well or predict the behavior. “Are you going to contribute to the United Fund this year?” is notorious in that over twice the percentage of respondents respond positively than actually contribute. If nuclear images are overwhelmingly negative (Slovic et al., 1991), there might be a socially desirable element in responding negatively to questions related to nuclear facilities (Noelle-Neumann, 1993) regardless of actual opinions.

Even if the attitude measures are accurate, holding negative images of nuclear facilities is not a good predictor of decisions, in part because the attitude is neither potent nor salient to most people. The studies of intentions ask questions now about behavior years in the future. In the absence of accidents, there is little reason to expect attitudes about the repository and transportation of spent nuclear fuel and high-level radioactive waste to ever be salient to most Nevadans and to most people considering vacationing in southern Nevada.

- **People do not seek to minimize risks, but to avoid significant threats to their health and safety.**

In assessing public perceptions of a high-level radioactive waste repository or other technologies often viewed as risky among the general public, there is a tendency to assume that everyone’s goal is to minimize risks. The reality is much more complex as people often prefer riskier activities (e.g., skiing, wilderness hiking) more than safer ones and more dangerous vacation destinations over safer places. There is a substantial literature explaining why some risks are acceptable and others unacceptable (e.g., Slovic, 1999). What matters in terms of motivating behavior are risk perceptions that oneself or one’s family might actually be harmed, not any desire for the lowest possible level of risk *per se*. What is important is not whether people think a repository would be riskier for Nevadans than the No-Action Alternative, but whether they think there is a meaningful likelihood that the repository or the transportation of spent nuclear fuel and high-level radioactive waste will harm them.

- **The theory of the “social amplification of risk,” as applied to the proposed repository and transportation of spent nuclear fuel and high-level radioactive waste, is that the consequences of an accident at Yucca Mountain or in transporting these materials would extend beyond the immediate victims. The theory is that an accident would result in people thinking about possible risks associated with the repository and transportation, and taking actions intended to reduce risks.**

Slovic et al. (1991) summarizes:

> “The informativeness or signal potential of a mishap, and thus its potential social impact, appears to be systematically related to the perceived characteristics of the hazard. An accident that takes many lives may produce relatively little social disturbance (beyond that caused to the victims’ families and friends) if it occurs as part of a familiar and well-understood system (e.g., a train wreck). However, a small accident in an unfamiliar system (or one perceived as poorly understood), such as a nuclear waste repository or a recombinant DNA laboratory, may have immense social consequences if it is perceived as a harbinger of future and possibly catastrophic mishaps” (1991, 685).

According to the theorists (Kasperson et al., 1988) who developed the theory of the “social amplification of risk,” the mere existence of a facility such as a repository will neither raise fears nor influence decisions. An accident is needed to generate the process that amplifies risk perceptions and related behavior.

The theory of the "social amplification of risk" is only relevant to assessing the link between attitudes and behavior if there were to be an accident at Yucca Mountain or in transporting spent nuclear fuel and high-level radioactive waste. The theory provides a plausible explanation of how an accident could make attitudes salient and lead to behavior consistent with those attitudes.

- **"Stigma" theory, as applied to the proposed repository and transportation of spent nuclear fuel and high-level radioactive waste, is that the consequences of an accident at Yucca Mountain or in transporting these materials would lead to a widely-held negative stereotype of southern Nevada so that (1) many businesses and people would decide to locate elsewhere and (2) many erstwhile and potential vacationers to southern Nevada would also go elsewhere.**

Stigma is "… a social construction that involves at least two fundamental components: (1) the recognition of difference based on some distinguishing characteristic, or 'mark'; and (2) a consequent devaluation..." (Dovidio, Major, and Crocker 2000, 3). Slovic et al. (1991) argue that places as well as people can be stigmatized. They suggest that images of nuclear facilities are so negative that an accident at Yucca Mountain or during transportation would trigger such a high level of concern that the entire region would become stigmatized. Slovic, Flynn, and Gregory write, "… the theory put forth to predict impacts conditions such impacts on the occurrence of *key events* that trigger negative images that, in turn, motivate individual, social, and institutional responses" (1994, 775).

Easterling reiterates:

> "Is the prospect of this facility more aversive than will be true of the actual facility? The answer will depend on whether people grow accustomed to the repository (i.e., become desensitized to the current connotations) once the facility becomes a reality. This, in turn, will likely hinge on the track record of the repository once it becomes operational; an accident-prone facility would reinforce the pre-existing attributions, whereas an uneventful track record may defuse the fears that are currently associated with a repository" (Easterling 2001, 142).

Stigma theory is a variant of the "social amplification of risk." Both are relevant to assessing the link between attitudes and behavior only if there were to be an accident at Yucca Mountain or in transporting spent nuclear fuel and high-level radioactive waste. Stigma provides a plausible explanation of how an accident could make attitudes salient and lead to behavior consistent with those attitudes. As Slovic and Flynn write, "…our aim (with stigma research) was to demonstrate a *mechanism*, grounded in theory and data, by which substantial impacts could occur—just as they have occurred with some hazardous waste sites and some other events—such as the Tylenol scare" (1991, 701). If there are no significant accidents in the operation of the repository and with transportation, there is no reason for stigma to happen.

5.0 Linking Risk Perceptions and Behavior to Socioeconomic Impacts

This section links the perception and behavior research to socioeconomic impacts.

- **Perceptions about a repository and transportation of spent nuclear fuel and high-level radioactive waste are unlikely to engender behavior that will harm the Nevadan economy.**

The mainstay of the economy of southern Nevada involves tourism and other services in the Las Vegas area. Absent serious accidents, there is little reason to expect the repository program to discourage businesses and persons considering moving to southern Nevada, or vacationers.

Even if there is a serious accident, stigmatization might not happen. Hershey Park, a large amusement park 11 miles from Three Mile Island, continues to set attendance records. The area directly downwind of Three Mile Island has had the most economic growth of any Pennsylvania region since the 1979 accident.

The mere presence of radioactive waste does not necessarily discourage tourism. Disneyland is 35 miles from San Onofre, where at-reactor storage of spent nuclear fuel takes place. In 2000, 38 million tourists visited New York City, which is less than 90 miles from a nuclear power plant with at-reactor storage.

- **The eco-tourism segment of the southern Nevada economy appears most vulnerable to adverse socioeconomic impacts from perceptions.**

Eco-tourism is travel and visitation to relatively undisturbed natural areas in order to enjoy and appreciate nature in a manner that promotes conservation. Jenkins-Smith (2001) presents data that suggests that the people most likely not to visit Nevada because of the repository have values similar to eco-tourists. Absent accidents, therefore, the segment of the southern Nevada economy most vulnerable to perception impacts might be the eco-tourism industry. Eco-tourism at present does not appear to be a large component of the southern Nevada economy.

- **Both stigma and the social amplification of risk require a trigger (e.g., a major accident) to bring about behavioral changes and adverse socioeconomic impacts.**

If there are no serious accidents, there will be no stigma and no social amplification of risk.

- **The repository would not reduce property values.**

The closest analogies we have to the proposed repository are low-level waste facilities, Federal nuclear reservations (e.g., Hanford), the Waste Isolation Pilot Project, and nuclear power plants. There is little evidence of negative impacts on property values in the vicinity of nuclear facilities, even Three Mile Island, site of America's most publicized nuclear accident (Gamble, Downing, and Sauerlender, 1980; Gamble and Downing, 1982; Nelson 1981). Impacts that have occurred (e.g., the area of the Fernald weapons plant in Ohio) are linked to contamination, not the mere presence of nuclear facilities. Hunsperger (2001) and Feiertag (1992) suggest that contaminated Federal facilities have impacts similar to those of Superfund sites.

- **Perceptions might temporarily reduce property values along urban transportation corridors by approximately 3 percent, although other research shows that impacts might be negligible or nonexistent.**

The UER (2001) and Gawande and Jenkins-Smith (2001) studies suggest that, at least temporarily, residential property values in transportation corridors in urban areas may decline approximately 3 percent. Data from other transportation experiences (e.g., transuranic waste to WIPP) suggest that impacts on property values might be negligible or nonexistent.

6.0 Conclusions

There is a consensus among social scientists that a quantitative assessment of the potential impacts from risk perceptions of the proposed repository and the transportation of spent nuclear fuel and high-level radioactive waste is impossible at this time and probably unlikely even after extensive additional research. The implication is not that impacts would probably be large, but simply difficult to quantify. As the NWTRB noted in 1995, social scientists do not know enough to identify what would be the level of concern during the operation of a repository, if it does open. Similarly, we cannot specify the links between those attitudes and individual decisions that would have socioeconomic impacts. Based upon what we do know from surveys and from analogues, we can assess qualitatively what outcomes seem most likely.

6.1 Effects from Perceptions of the Proposed Repository

Social scientists are loath to write that something in the future is impossible. Thinking like science fiction authors, social scientists can conjure sequences of extremely unlikely events that, taken together, can result in tragic consequences.

The answers to questions about socioeconomic impacts from perceptions vary by how the question is phrased. If the question asks if significant adverse socioeconomic impacts are possible if the repository were to open, the answer of course is affirmative, even without science fiction. The more useful question asks whether there is a reasonable likelihood that perceptions about an operating repository are likely to engender significant adverse socioeconomic impacts. In the absence of a large accident at the repository or a continuing series of smaller accidents, there is little reason to expect significant adverse effects:

- Although, when asked, many people report that they think of nuclear things as dangerous, these attitudes are usually not salient in people's lives and therefore do not influence personal decisions. People do not consider that spent nuclear fuel is stored at San Onofre when they decide whether to visit Disneyland.

- Yucca Mountain is not in Las Vegas, but a significant distance away in the desert.

- Studies show few indications of adverse socioeconomic effects (and many positive socioeconomic effects) in places that currently safely store or dispose of radioactive waste. As New Mexico has not become stigmatized as the "transuranic nuclear waste dump state," there is little reason to expect that Nevada would be stigmatized.

- People who choose to vacation in Las Vegas are less likely to be concerned about the repository than people who choose to vacation elsewhere. Opening the repository, if there is any impact, would be likely to re-enforce the preferences of people who do not intend to visit Las Vegas with or without an operating repository 90 miles away. People who do like to visit Las Vegas would likely pay little attention.

- If the repository would be such a powerful disincentive to investors, businesses considering relocating to southern Nevada, and retirees and others considering relocating in the area, some effects of those perceptions should already be apparent. It is widely known that Congress has ordered DOE to characterize Yucca Mountain for consideration for a repository and that key program documents suggest that the site might be acceptable. If a repository were such a powerful disincentive, prudent investors, facing a possible opening of a repository, would not be investing in southern Nevada. Similarly, we would see a decline in population in southern Nevada as businesses and people decide to settle elsewhere in anticipation of future risks and stigma. There is no evidence of this behavior.

The assessment that substantial adverse socioeconomic impacts from perceptions of the repository are quite unlikely assumes that operations at the facility will not have either a major accident (e.g., an explosion with a significant release of ionizing radiation bringing about exposures downwind, some cases of radiation poisoning, and deaths) or periodic smaller accidents (e.g., damaged canisters with some releases of ionizing radiation). These events would most likely raise fears about a repository, make a repository salient to people in southern Nevada, result in some social amplification of risk, and perhaps even stigmatize the region. Adverse socioeconomic effects from perceptions of an accident-prone repository might be substantial even with the repository 90 miles away. Without nuclear accidents at Yucca Mountain, these effects are quite unlikely.

6.2 Effects from Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste

As with socioeconomic impacts from perceptions about a repository, the answers to questions about potential impacts from the transportation of spent nuclear fuel and high-level radioactive waste vary with how the question is posed. Are significant adverse impacts possible? Large impacts are possible if there are accidents with releases of ionizing radiation during the transportation of spent nuclear fuel and high-level radioactive waste. The social amplification and risk and stigma might become quite relevant after an accident that exposes neighborhoods to ionizing radiation.

A different question is whether there is a reasonable likelihood that perceptions about transporting spent nuclear fuel and high-level radioactive waste are likely to engender significant adverse socioeconomic impacts. Absent accidents, there is no reason to expect impacts for property owners in areas beyond the transportation corridors. Even absent accidents, however, some studies (UER 2001; Gawande and Jenkins-Smith 2001) report that, at least temporarily, a decline in residential property values of approximately 3 percent might be expected in transportation corridors in urban areas. Data from other transportation experiences (e.g., transuranic waste to WIPP) suggest that impacts on property values might be negligible or nonexistent. More research on whether property values have fluctuated, and for how long, with the transportation of radioactive materials would be beneficial, although the research would not allow analysts to know with certainty whether there would be any impacts from perceptions of shipments of spent nuclear fuel and high-level radioactive waste to a Yucca Mountain Repository.

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United States Department of the Interior

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August 28, 2001
File No. 1-5-00-F-518

Mr. Stephan Brocoum, Assistant Manager
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North Las Vegas, Nevada 89036-0307

Dear Mr. Brocoum:

Subject: Final Biological Opinion for the Effects of Construction, Operation and Monitoring, and Closure of a Geologic Repository at Yucca Mountain, Nye County, Nevada

This document transmits the U.S. Fish and Wildlife Service's (Service) final biological opinion based on our review of the proposed construction, operation and monitoring, and closure of a geologic repository at Yucca Mountain, Nye County, Nevada, and its effects on the federally-threatened Mojave desert tortoise (*Gopherus agassizii*) in accordance with section 7 of the Endangered Species Act of 1973, as amended (Act) (16 U.S.C. 1531 *et seq.*). Your April 24, 2000, request for formal consultation was received on May 1, 2000.

This biological opinion is based on information provided in the April 2000 biological assessment (Department of Energy [DOE] 2000a); DOE correspondence to the Field Supervisor, Nevada Fish and Wildlife Office dated April 24, 2000, September 22, 2000, October 12, 2000, February 15, 2001 (DOE 2001a), April 5, 2001 (DOE 2001b), June 12, 2001, and August 22, 2001; DOE's August 2000 correspondence with the National Marine Fisheries Service; draft environmental impact statement (DEIS) dated July 1999 (DOE 1999); biological opinions for site characterization studies at Yucca Mountain (File Nos. 1-5-90-F-6 and 1-5-96-F-307R); meetings between a DOE representative and Service staff on September 11, 1998, and March 18, 1999; conversations with DOE and representative staff; and our files. A complete administrative record of this consultation is on file in the Southern Nevada Field Office.

Consultation History

On February 9, 1990, the Service issued a non-jeopardy biological opinion to DOE for site characterization studies at Yucca Mountain (File No. 1-5-90-F-6). In the biological opinion, the

Service required DOE to continue their 1989 desert tortoise monitoring program (DOE 1989) which included the following objectives: (1) Determine relative abundance and distribution of desert tortoises on the project site, (2) implement a long-term program to monitor the relative abundance of tortoises at Yucca Mountain and the effects of site characterization activities on the species, (3) monitor the presence of any disease in desert tortoises, (4) study the movements and habitat use of desert tortoises and develop a model of desert tortoise habitat, (5) conduct field studies to determine the efficacy of relocating tortoises to new areas, (6) conduct field studies to determine the efficacy of fences and underpasses along roads to prevent vehicles from killing tortoises, and (7) monitor populations of ravens and other desert tortoise predators. These studies were conducted by DOE and their contractors at the estimated cost of $4 million (DOE 2001b). A list of reports, publications, and abstracts provided by DOE in their April 5, 2001, letter (DOE 2001b) identifies the reference documents for these studies.

In the 1990 biological opinion, the Service determined that approximately 15 desert tortoises might be affected within the 450-acre project area. Subsequently, it became apparent that the estimated number of tortoises encountered at the project site was higher than anticipated in the previous biological opinion. On February 22, 1995, the Service requested that DOE request reinitiation of consultation for site characterization studies. By Service letter to DOE dated September 18, 1996, following the August 7, 1996, meeting among DOE and Service staff, it was mutually agreed between DOE and the Service that the continuation of project activities at Yucca Mountain would not result in DOE expenditures, studies, or monitoring in excess of those stipulated in the 1990 biological opinion (Service 1996). The Service reinitiated formal consultation on December 9, 1996, and issued a new biological opinion to DOE on July 23, 1997 (File No. 1-5-96-F-307R). This reinitiated biological opinion shall remain in effect until site characterization studies are completed.

On December 17, 1998, and February 4, 2000, DOE requested an updated species list for the project area, which was provided by the Service on January 21, 1999, (File No. 1-5-99-SP-059) and February 25, 2000 (File No. 1-5-00-SP-440), respectively.

In your April 24, 2000, letter, DOE determined that transportation of nuclear materials will involve routine transportation methods and routes and will insignificantly increase traffic volumes. Thus, DOE determined that transportation of nuclear materials from the 77 sites identified in the biological assessment will result in "no effect" to federally listed species.

DOE evaluated the potential effects to 47 federally-listed species from transportation of nuclear materials from various sites across the nation to Yucca Mountain which may involve the use of barges in the marine environment (DOE 2000b). In their DEIS, DOE showed that the likelihood of an accident involving spent nuclear fuel on a marine barge is extremely small, and the further likelihood of an accident resulting in release of radioactivity is even smaller. Because the locations of accidents would be random, the likelihood that threatened and endangered species would be involved is reduced further. Based on these analyses, DOE concluded that the likelihood of these improbabilities resulting in an accident that may affect listed species or critical habitat, is so small that it can be considered discountable. Subsequently, on August 17, 2000, DOE determined that only the desert tortoise may be affected by the subject project (DOE 2000b).

The Service initiated formal consultation upon receipt of your request on May 1, 2000. On September 13, 2000, the Service requested a 60-day extension of the consultation period. DOE concurred with the request by letter dated September 22, 2000. Subsequently, DOE requested that the consultation period be extended to approximately November 15, 2000, to allow DOE time to refine the level of disturbance anticipated as a result of the proposed action. On February 22, 2001, the Service received DOE's modifications to the previous project description that would result in an additional 1,100 acres of disturbance of desert tortoise habitat (DOE 2001b). In response, the Service requested additional information on February 23, 2001, on the potential effects to desert tortoise that may result from the proposed modification. DOE provided that information by correspondence dated April 5, 2001 (DOE 2001a).

On May 8, 2001, the Service issued a draft biological opinion to DOE on the subject project and requested comments on the draft by May 18, 2001. On May 23, 2001, DOE requested that the deadline for comments be extended to June 15, 2001, and the opportunity to review the draft biological opinion before it is finalized. The Service concurred and received DOE's comments on the draft biological opinion on June 15, 2001. A second draft biological opinion was issued to DOE on July 26, 2001. On August 22, 2001, DOE submitted a letter to the Service stating that DOE has no further comments on the draft opinion and requested a final biological opinion on the subject project.

Description of the Proposed Action

The DOE proposes to construct, operate and monitor, and eventually close a geological repository on the Nevada Test Site (NTS) and surrounding lands at Yucca Mountain, Nevada, for the disposal of approximately 77,000 tons of commercial and DOE owned nuclear waste. The project site is located in a remote area of southern Nye County, Nevada, approximately 93 miles northwest of Las Vegas, Nevada Figure 1). Construction, operation and monitoring, and closure of the repository will require the active use of up to 1,643 acres of land, in addition to areas used during site characterization studies, and up to 430 acre-feet of groundwater per year. The nuclear waste would consist of spent nuclear fuel and high-level nuclear waste (HLW) presently stored at 72 commercial nuclear power generating facilities and 5 DOE facilities. These materials would be transported to a repository at Yucca Mountain using a combination of methods including barges, legal-weight trucks, heavy haul trucks, and rail. *Legal-weight trucks* have a gross vehicle weight of less than 40 tons which is the loaded weight limit for commercial vehicles operated on public highways without special state-issued permits. *Heavy-haul trucks* are overweight, over-dimension vehicles that must have permits from state highway authorities to use public highways.

The project includes the repository site (Figure 2), potential corridors within Nevada and an approximately 6-mile-long segment in California where a branch rail line may be constructed (Figure 3), potential intermodal transfer station sites (Figure 4), and potential heavy-haul routes, including areas where necessary highway upgrades may occur (Figure 5). The specific method and route of transport has not been determined at this time, therefore, the potential effects to desert tortoise that may result from transportation of materials, including construction of transportation infrastructure, will be evaluated in future consultations under section 7 of the Act. Future Federal actions will be required for proposed transportation of materials associated with the subject project including issuance of right-of-way grants and/or acquisition and expenditure of Federal highway funds. The Service anticipates that DOE would comply with the terms and conditions of biological opinions issued to other Federal agencies, as appropriate, for future transportation projects associated with the repository.

Repository Construction

DOE proposes to construct and use above- and below-ground facilities. The construction phase would likely include new construction, modification, and maintenance of infrastructure (e.g., electrical and water lines); construction of roads, buildings, parking areas, sanitary waste lines and drain fields; borrow pits; evaporation ponds; topsoil and rock storage areas; storm water retention basins; a solid waste landfill; a surface aging area; ventilation shafts; a solar power system; and underground tunnels. These facilities would be required to support receipt and repackaging of spent nuclear fuel (SNF) and HLW into waste packages, placing waste packages underground, maintaining a capability to retrieve the waste packages if needed, monitoring, and closing the repository. Most facilities developed to process SNF and HLW, and support construction of the below-ground facilities would be located in the North Portal Operations Area, the South Portal Development Operations Area, the Emplacement Ventilation Shaft Area, and the Development Ventilation Shaft Area (Figure 2).

Excavated rock (muck) from the repository would be transported through the South Portal and moved to a muck storage area on or near Midway Valley or Jackass Flats using trucks or an overland conveyor system. Site water would come from NTS J-12, J-13, and C wells, south and southeast of the North Portal Operations Area. The wells and distribution piping to the repository already exist, however additional infrastructure may be required and routine maintenance would be performed. Sanitary sewage would be routed to septic tank/leach field wastewater-treatment systems which would be established near the facilities using them.

DOE is considering constructing a 3-megawatt solar power generating facility to meet the energy requirements of the proposed repository. The solar facility would likely be located in Midway Valley, 1.2 to 2.5 miles east or northeast of the North Portal Operations Area (Figure 2). Approximately 25 acres would be disturbed during construction of the facility and access road. A power transmission line connecting the facility to the North Portal would likely be constructed within an existing, previously disturbed right-of-way. The solar facility would be built in phases of 500 kilowatts per year, starting in 2005, and would likely be connected to the site power distribution system.

It is possible that regulatory changes would allow up to 11,000 tons of SNF and HLW to be received before the start of underground emplacement of waste packages. In this case, a concrete pad, associated facilities, and infrastructure would be constructed in or near Midway Valley for temporary holding prior to being placed underground.

Construction of the repository facilities could begin only after receipt of construction authorization from the Nuclear Regulatory Commission. DOE estimates that construction may begin in 2005. The repository surface facilities, main drifts, ventilation system, and initial emplacement drifts would be built in approximately 5 years, from 2005 to 2010. Beginning in 2010, the older and cooler commercial spent nuclear fuel could be loaded into waste packages and emplaced into the repository. Construction of emplacement drifts would continue until approximately 2032.

Repository Operation and Monitoring

Above-ground facilities would be used to receive, prepare, and repackage SNF and HLW for placement into the below ground repository. Unloading, handling, and repackaging of material would occur in a radiologically-controlled area, and would be controlled remotely. Secondary wastes generated by repository operations would include low-level radioactive, hazardous, sanitary, and industrial solid wastes. Although unlikely, small amounts of low-level mixed radioactive waste could be generated. Some wastes could be processed and/or packaged onsite. All low-level and low-level mixed waste would be shipped offsite for disposal. Hazardous waste would be packaged and shipped offsite for treatment and disposal. Industrial waste would be disposed of either offsite or in a landfill developed in the Yucca Mountain area. Sanitary liquid waste would be processed through the sanitary waste water system. Ventilation exhaust from the repository would be a mixture of hot air (approximately 310^0 F) from the closed emplacement drifts, and cooler air from the open drifts where waste packages would be emplaced.

Closure/Post Closure

Closure of the repository and facilities may include decommissioning buildings and equipment; removal of equipment and other materials from the site; backfilling of the main drifts, ramps, shafts and connecting openings; and final site reclamation. Reclamation may include recontouring disturbed areas, surface backfill, soil buildup and reconditioning, site vegetation, site water course configuration, and erosion control.

Heat generated from the emplaced SNF and HLW is expected to warm the surrounding rock and soil above the repository over 750 to 2,500 acres. Increases in soil temperature are expected to begin about 200 years after waste package emplacement in the repository, and to reach maximum levels in about 700 years. DOE estimates that the temperature increase would be approximately 0.7^0 F for wet soil and 5^0 F for dry soil. The repository is designed with the capability for closure as early as 50 years, or as late as 300 years, after the start of emplacement. The period to accomplish closure would range from 6 to 15 years.

Transportation Options

The national routes taken to transport SNF and HLW to the repository would occur on the existing national transportation infrastructure of waterways, highways, and railroads. The exceptions to this are the potential construction of a branch rail line in Nevada and approximately 6 miles in California (Jean rail corridor option), potential construction of an intermodal transfer station in Nevada for the transfer of rail shipments to heavy-haul trucks, and potential modification of existing highways within Nevada to allow travel of heavy-haul trucks. For transport within Nevada, three options were considered by DOE which include (1) mostly legal-weight trucks, (2) mostly heavy-haul trucks, and (3) mostly rail.

If the rail transport option within Nevada is chosen to transport SNF and HLW to the repository, construction of a branch rail system would be required to connect the mainline rail with Yucca Mountain. If heavy-haul trucks are used, an intermodal transfer facility would be constructed where shipments would be transferred from rail cars to heavy-haul trucks for final shipment to the repository at Yucca Mountain. Five branch rail line corridors, five potential heavy-haul routes, and three general sites for potential intermodal transfer facilities have been identified within Nevada (Figure 4). Two of the three transfer facilities occur within the range of the desert tortoise but outside any areas designated for recovery of the species. The use of legal-weight truck transportation would not require construction. Legal-weight trucks would enter Nevada on

Interstate 15 from either the north or south, travel through the Las Vegas area using beltways currently under construction, and travel north on a U.S. Highway to Yucca Mountain.

Rail branch or intermodal transfer facility construction, or highway modifications will require Federal authorization or funding and, therefore, will be subject to future consultation under section 7 of the Act with the appropriate Federal agency such as the Bureau of Land Management (BLM) or the Federal Highway Administration. At that time, potential effects to desert tortoise will be identified and evaluated under the appropriate consultation procedures.

As minimization measures, DOE (2000a, 2001b) proposes the following measures to minimize effects to desert tortoises from the proposed action, which include the following:

1. All DOE and contractor personnel working at Yucca Mountain and on transportation construction projects within the range of the desert tortoise will complete a desert tortoise education program. This program will explain the legal status of desert tortoises, the definition of "take," and penalties for violations of Federal and State laws regarding tortoises. The program will include information on the life history of the desert tortoise and general tortoise activity patterns, what to do if a tortoise is sighted (including how to safely move tortoises off roads), and an explanation of measures designed to protect tortoises (e.g., speed limits, prohibition of off-road driving, etc.).

2. Clearance surveys will be conducted prior to clearing of vegetation at previously undisturbed sites if new disturbances are larger than 5 acres. Most areas where disturbances will take place have a low abundance of tortoises and the likelihood of finding tortoises in sites less than 5 acres in size is small. In addition, most smaller disturbances would be distant from larger disturbances, be short in duration, and would involve minimal equipment.

3. A tortoise biologist or environmental monitor will be available during construction activities to help ensure that desert tortoises are not inadvertently harmed. Project activities that may endanger a tortoise will cease if a tortoise is found on a project site. Project activities will resume only after a biologist or environmental monitor ensures that the tortoise is not in danger or after the tortoise has moved to a safe area.

4. All vehicles will be driven at speeds within the posted speed limits on existing roads, and will not exceed 25 miles per hour on unposted roads. Vehicles will not be driven off existing roads in non-emergency situations unless authorized by DOE. During the tortoise activity season (February 16 through November 14) the proposed vehicle path will be cleared of tortoises immediately prior to off-road travel. During the tortoise

inactive season, the proposed vehicle path will be cleared of tortoises within 7 days prior to off-road travel.

5. A litter-control program will be implemented that will include the use of covered trash receptacles, disposal of edible trash in trash receptacles following the end of each work day, and disposal of trash in a designated sanitary landfill. Any material placed in a sanitary landfill operated by the Yucca Mountain project will be covered often enough to prevent scavengers and predators from feeding there.

6. All non-linear habitat disturbances larger than 2.5 acres at Yucca Mountain which have had vegetation removed but no longer being used will be revegetated in accordance with the *Reclamation Implementation Plan* (DOE 1995) and the *Reclamation Standards and Monitoring Plan* (RSMP) (DOE 1998). These plans may include specifications for contouring, relieving soil compaction, treating and/or spreading topsoil, seeding, and using transplants.

Status of the Species- Rangewide

The desert tortoise is a large, herbivorous reptile found in portions of California, Arizona, Nevada, and Utah. It also occurs in Sonora and Sinaloa, Mexico. The Mojave population of the desert tortoise includes those animals living north and west of the Colorado River in the Mojave Desert of California, Nevada, Arizona, southwestern Utah, and in the Colorado Desert in California. Desert tortoises reach 8 to 15 inches in carapace length. Adults have a domed carapace and relatively flat, unhinged plastron. Shell color is brownish, with yellow to tan scute centers. The forelimbs are flattened and adapted for digging and burrowing. Optimal habitat has been characterized as creosote bush scrub in which precipitation ranges from 2 to 8 inches, where a diversity of perennial plants is relatively high, and production of ephemerals is high (Luckenbach 1982, Turner 1982, Turner and Brown 1982). Soils must be friable enough for digging of burrows, but firm enough so that burrows do not collapse. Desert tortoises occur from below sea level to an elevation of 7,300 feet, but the most favorable habitat occurs at elevations of approximately 1,000 to 3,000 feet (Luckenbach 1982).

Desert tortoises are most active during the spring and early summer when annual plants are most common. Additional activity occurs during warmer fall months and occasionally after summer rain storms. Desert tortoises spend the remainder of the year in burrows, escaping the extreme conditions of the desert. The size of desert tortoise home ranges vary with respect to location and year. Females have long-term home ranges that are approximately half that of the average male, which range from 25 to 200 acres (Berry 1986). Over its lifetime, each desert tortoise may require more than 1.5 square miles of habitat and make forays of more than 7 miles at a time (Berry 1986). In drought years, the ability of tortoises to drink while surface water is available following rains may be crucial for tortoise survival. During droughts, tortoises forage over larger areas, increasing the likelihood of encounters with sources of injury or mortality including humans and other predators. Desert tortoises possess a combination of life history and reproductive characteristics which affect the ability of populations to survive external threats. Tortoises may require 20 years to reach sexual maturity (Turner et al. 1984; Bury 1987).

The desert tortoise is most commonly found within the desert scrub vegetation type, primarily in creosote bush scrub. In addition, it is found in succulent scrub, cheesebush scrub, blackbrush scrub, hopsage scrub, shadscale scrub, microphyll woodland, Mojave saltbush-allscale scrub, and scrub-steppe vegetation types of the desert and semidesert grassland complex (Service 1994). Within these vegetation types, desert tortoises potentially can survive and reproduce where their basic habitat requirements are met. These requirements include a sufficient amount and quality of forage species; shelter sites for protection from predators and environmental extremes; suitable substrates for burrowing, nesting, and overwintering; various plants for shelter; and adequate area for movement, dispersal, and gene flow. Throughout most of the Mojave Region, tortoises occur most commonly on gently sloping terrain with soils ranging from sand to sandy-gravel and with scattered shrubs, and where there is abundant inter-shrub space for growth of herbaceous plants. Throughout their range, however, tortoises can be found in steeper, rockier areas. Further information on the range, biology, and ecology of the desert tortoise can be found in Berry and Burge (1984); Burge (1978); Burge and Bradley (1976); Bury et al. (1994); Germano et al. 1994; Hovik and Hardenbrook (1989); Karl (1981, 1983a, 1983b); Luckenbach (1982); Service (1994); and Weinstein et al. (1987).

On August 4, 1989, the Service published an emergency rule listing the Mojave population of the desert tortoise as endangered (54 FR 42270). On April 2, 1990, the Service determined the Mojave population of the desert tortoise to be threatened (55 FR 12178). Reasons for the determination included loss of habitat from construction projects such as roads, housing and energy developments, and conversion of native habitat to agriculture. Grazing and off-highway vehicle (OHV) activity have degraded additional habitat. Also cited as threatening the desert tortoise's continuing existence were illegal collection by humans for pets or consumption, upper respiratory tract disease (URTD), predation on juvenile desert tortoises by common ravens (*Corvus corax*) and kit foxes (*Vulpes macrotis*), and collisions with vehicles on paved and unpaved roads. Fire is an increasingly important threat to desert tortoise habitat. Over 500,000 acres of desert lands burned in the Mojave Desert in the 1980s. Fires in Mojave desert scrub degrade or eliminate habitat for desert tortoises (Appendix D of Service 1994).

On February 8, 1994, the Service designated approximately 6.4 million acres of critical habitat for the Mojave population of the desert tortoise in portions of California, Nevada, Arizona, and Utah (59 FR 5820), which became effective on March 10, 1994. Critical habitat is designated by the Service to identify the key biological and physical needs of the species and key areas for recovery, and focuses conservation actions on those areas. Critical habitat is composed of specific geographic areas that contain the primary constituent elements of critical habitat, consisting of the biological and physical attributes essential to the species' conservation within those areas, such as space, food, water, nutrition, cover, shelter, reproductive sites, and special habitats. The specific primary constituent elements of desert tortoise critical habitat are: Sufficient space to support viable populations within each of the six recovery units (RUs), and to provide for movement, dispersal, and gene flow; sufficient quality and quantity of forage species and the proper soil conditions to provide for the growth of these species; suitable substrates for burrowing, nesting, and overwintering; burrows, caliche caves, and other shelter sites; sufficient vegetation for shelter from temperature extremes and predators; and habitat protected from disturbance and human-caused mortality.

Approximately 1.2 million acres were designated as critical habitat in Nevada. Critical habitat units (CHUs) were based on recommendations for Desert Wildlife Management Areas (DWMAs) outlined in the *Draft Recovery Plan for the Desert Tortoise (Mojave Population)* (Service 1993). These DWMAs are also identified as "desert tortoise areas of critical environmental concern (ACECs)" by the BLM. Because the CHU boundaries were drawn to optimize reserve design, the CHU may contain both "suitable" and "unsuitable" habitat. Suitable habitat can be generally defined as areas that provide the primary constituent elements. The Yucca Mountain project area does not occur within desert tortoise critical habitat.

On June 28, 1994, the Service approved the final Desert Tortoise Recovery Plan (Service 1994). The Desert Tortoise Recovery Plan divides the range of the desert tortoise into 6 RUs and recommends establishment of 14 DWMAs throughout the RUs. Within each DWMA, the Desert Tortoise Recovery Plan recommends implementation of reserve-level protection of desert tortoise populations and habitat, while maintaining and protecting other sensitive species and ecosystem functions. The design of DWMAs should follow accepted concepts of reserve design. As part of the actions needed to accomplish recovery, the Desert Tortoise Recovery Plan recommends that land management within all DWMAs should restrict human activities that negatively impact desert tortoises (Service 1994). DWMAs have been designated by the BLM through development or modification of their land use plans in Nevada, Arizona, and Utah. Land-use planning activities are underway in California to designate DWMAs/ACECs. The regulation of activities within critical habitat through section 7 consultation is based on recommendations in the Desert Tortoise Recovery Plan. DWMAs/ACECs have been designated in Utah, Arizona, and Nevada. Similar designations are in progress in California for the Western

Mojave RU, and Northern and Eastern Colorado RUs. Yucca Mountain occurs within the Northeastern Mojave RU near the boundary with the Eastern Mojave RU, but not within a proposed DWMA.

The Northeastern Mojave RU occurs primarily in Nevada, but it also extends into California along the Ivanpah Valley and into extreme southwestern Utah and northwestern Arizona. Vegetation within this unit is characterized by creosote bush scrub, big galleta-scrub steppe, desert needlegrass scrub-steppe, and blackbrush scrub (in higher elevations). Topography is varied, with flats, valleys, alluvial fans, washes, and rocky slopes. Much of the northern portion of the RU is characterized as basin and range, with elevations from 2,500 to 12,000 feet. Desert tortoises typically eat summer and winter annuals, cacti, and perennial grasses. Desert tortoises in this RU, the northern portion of which represents the northernmost distribution of the species, are typically found in low densities (approximately 10 to 20 adults per square mile).

Recovery of the desert tortoise may occur at the recovery unit level which allows populations within each of the six recovery units to be recovered and delisted individually. Similarly, the jeopardy and adverse modification standards may be applied within or across recovery units. Thus, proposals to implement the Desert Tortoise Recovery Plan in portions of a recovery unit cannot be evaluated with regard to jeopardy or adverse modification in a section 7 consultation without an understanding of proposed or existing management prescriptions occurring elsewhere in the recovery unit.

Long-term monitoring of desert tortoise populations is a high priority recovery task as identified in the Desert Tortoise Recovery Plan. From 1995 to 1998, pilot field studies and workshops were conducted to develop a monitoring program for desert tortoise. In 1998, the Desert Tortoise Management Oversight Group chose line distance sampling as the appropriate method to determine rangewide desert tortoise population densities and trends. Monitoring of populations using this method is underway across the range of the desert tortoise and baseline population data will be forthcoming within the next year. Successful rangewide monitoring will enable managers to evaluate the overall effectiveness of recovery actions and population responses to these actions, thus guiding recovery of the Mojave desert tortoise.

Environmental Baseline

The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation process.

Yucca Mountain is located in Nye County, Nevada, approximately 93 miles northwest of Las Vegas and crosses the jurisdictional boundaries of DOE, the U.S. Air Force (USAF), and BLM. The areas managed by the DOE and USAF have been reserved for use by government agencies in support of national security needs, and have been restricted from public access and grazing since the early 1950s (DOE 1997).

Yucca Mountain occurs on the northern edge of the Mojave Desert along an ecotone between the Great Basin and Mojave deserts with a maximum elevation of 4,950 feet. The area is characterized by three vegetation associations (DOE 1997). An association dominated by shrubs including primarily creosotebush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), spiny hopsage (*Grayia spinosa*), and Mormon tea (*Ephedra nevadensis*) is found on alluvial slopes in the Mojave Desert zone below approximately 4,265 feet. Mormon tea, spiny hopsage, and wolfberry (*Lycium andersonii*) dominate the vegetation association in the transition zone on alluvial slopes above approximately 4,265 feet and on the upper slopes of Yucca Mountain. The third vegetation association occurs on upper alluvial slopes and relatively level ridges, between approximately 3,800 and 4,950 feet is dominated by blackbrush (*Coleogyne ramosissima*) (DOE 1997).

Status of the Species in the Action Area

Karl (1989) conducted desert tortoise surveys in the Yucca Mountain area between September 17 and 23, 1989. A total of 23 strip transects were walked to assess distribution, habitat associations, and relative abundances of tortoise. According to the surveys, tortoises preferred large alluvial fans in the eastern portion of the area. Karl estimated that the density of desert tortoises ranged from 10 to 50 tortoises per square mile. The steep ridge/drainage mosaic in the western portion of Yucca Mountain had the least sign, and was considered poor habitat. Existing disturbance as a result of DOE activities in the Yucca Mountain area consisted of approximately 641 acres as a result of drill holes, trenches and test pits, seismic surveys, monitoring stations, bladed use facilities, and roads and corridors. The area with greatest disturbance was located along Drill Hole Wash Road. Additional disturbance was observed as a result of trespass cattle grazing.

Biologists with EG&G/Energy Measurements (EG&G/EM) (1991) conducted 341 transects from 1981 through 1984 in the Yucca Mountain area, covering approximately 322 linear miles. During the transects, 0.17 tortoise sign was found per mile of transect walked, including nine tortoises. Sign was found between 3,280 and 5,250 feet in elevation. Between 1987 and 1990, EG&G/EM biologists conducted additional transects during tortoise population and impact monitoring studies on the NTS. During these surveys, 54 desert tortoises were found at Yucca Mountain during 1989-1990 (EG&G/EM 1991). Based on transects and studies conducted from

1981 through 1995, DOE concluded that desert tortoises are widespread throughout Yucca Mountain and occur in all three of the common vegetation associations at Yucca Mountain (DOE 1997). Observational data recorded in the Yucca Mountain area during field work conducted from 1989 through 1995 suggest that desert tortoise densities are within the range of 10 to 50 per square mile presented by Karl (1989).

Between July 1991 and September 1995, biologists under contract to DOE monitored 95 radio telemetered tortoises to determine their location and behavior. Data collected during this monitoring program indicated that tortoises were inactive November 15 through February 15. During this period, tortoises were in burrows during 4,102 of 4,119 observations (Rautenstrauch et al. 1997). Because Yucca Mountain is located at higher elevations than average (approximately 3,200 to 4,950 feet) and at the northernmost distribution of the range of desert tortoise, these data may be different from inactive periods in other parts of the range of the desert tortoise. Based on the information above, the Service determined the tortoise active season at Yucca Mountain to be November 15 through February 15.

Major Activities Authorized Under Sections 7 and 10(a)(1)(A) of the Act in the Action Area

On February 9, 1990, the Service issued a non-jeopardy biological opinion to DOE for site characterization studies at Yucca Mountain (File No. 1-5-90-F-6) which was reinitiated on December 9, 1996, and superceded by a new biological opinion on July 23, 1997 (File No. 1-5-96-F-307R). A total of 375 acres of desert tortoise habitat has been disturbed of the 450 acres that DOE anticipated to disturb as a result of site characterization activities (DOE 2000a). During the site characterization studies, a total of five (5) desert tortoises were killed or injured, all of which were within the incidental for the 450-acre project area. Four (4) of these mortalities were the result of tortoise encounters with project-related vehicles. The fifth tortoise was a hatchling which fell into a project trench and died. An additional 28 tortoises were moved out of harm's way. Two of the displaced tortoises subsequently died; however, it was not determined to be a direct result of project activities.

On August 26, 1994, the Service issued a recovery permit (PRT-781234) to EG&G/EM under section 10(a)(1)(A) of the Act to conduct studies on hatchling and adult desert tortoises in Nevada and California which was originally covered under EG&G's prior permit, PRT-683011. In their 1989 biological assessment for the site characterization studies at Yucca Mountain (DOE 1989), DOE proposed to continue a desert tortoise population monitoring program initiated in 1989 at Yucca Mountain, which was incorporated by reference in the terms and conditions of the 1990 biological opinion. These studies were conducted by EG&G/EM under PRT-781234 at

Yucca Mountain and elsewhere on the NTS. Between 1989 and 1995, a total of 555 tortoises were captured and marked; 308 of these tortoises were radio telemetered. Effective December 31, 1995, EG&G/EM ended their contract with DOE for the Yucca Mountain Project and the permit was not renewed.

Programmatic Biological Opinions Issued for Desert Tortoise in Nevada

File No. 1-5-91-F-112. On September 26, 1991, the Service issued a programmatic biological opinion to the BLM's Las Vegas District for implementation of their Management Framework Plan (MFP) within the boundaries of Clark County's incidental take permit in the Las Vegas Valley. As a result of the action, approximately 42,240 acres of BLM land were authorized for disposal by sale, exchange, mineral leases, rights-of-way leases, or recreation or public purpose leases. These lands could be developed for residential, industrial, commercial, and public infrastructure projects to accommodate rapid urban development. The biological opinion concluded that the proposed action to implement the BLM's MFP was not likely to jeopardize the continued existence of the Mojave population of the desert tortoise; no critical habitat would be destroyed or adversely modified. Under the 1991 programmatic biological opinion, the BLM disposed of 5,252 acres out of the 42,240 acres originally identified.

File No. 1-5-96-F-023R. In order to expand the programmatic boundary from 263,267 acres to 378,978 acres to accommodate the rapid urban development in the Las Vegas Valley and surrounding area, the BLM reinitiated consultation on their 1991 programmatic biological opinion described above. On April 11, 1996, the Service issued a programmatic biological opinion to the BLM's Las Vegas District for implementation of their MFP and the land exchange portion of their Stateline Resource Management Plan within the Las Vegas Valley. Implementation of these plans, when finalized, may result in disposal or development of approximately 125,000 acres of land administered by the BLM by sale, land exchange, or lease. As a result of urban expansion, most BLM lands within the Las Vegas Valley are highly fragmented and impacted by human activities, particularly a 4,000-acre "exclusionary" zone. The BLM delineated an exclusionary zone within the programmatic boundary which does not contain suitable desert tortoise habitat. Except for lands within the exclusionary zone, the BLM will collect a mitigation fee of $623 per acre, as indexed for inflation, to compensate for the loss of tortoise habitat within the programmatic boundary. The fees will be used to fund management actions which are expected to provide direct and indirect benefits to the desert tortoise over time, which will assist in its recovery. This opinion remains in effect.

File No. 1-5-96-F-33. On August 22, 1996, the Service issued a biological opinion to the Department of Energy/Nevada Operations (DOE/NV) for programmatic activities on the NTS over the next 10 years, excluding the Yucca Mountain Project. The NTS occupies 1,350 square miles in Nye County, approximately 65 miles northwest of Las Vegas. All land on the NTS is managed by DOE/NV, and access is strictly controlled. Between 3,000 and 4,000 people work at the NTS, with the majority residing in Mercury, Nevada. Although large parts of the NTS have been affected by human activities, the majority of the site remains relatively undisturbed. Most disturbances are concentrated in the bottom of Yucca, Frenchman, and Jackass Flats, and on parts of the Pahute and Rainer Mesas. In the biological opinion, the Service concluded that up to 13 desert tortoises may be taken per year (3 mortalities or injuries and 10 captures/displacements from harm's way) as a result of DOE/NV activities, and a total of 3,015 acres of desert tortoise habitat may be disturbed during project construction over the 10-year period.

File No. 1-5-97-F-251. On November 21, 1997, the Service issued a programmatic biological opinion to the BLM for implementation of multiple-use actions within their Las Vegas District, excluding desert tortoise critical habitat, proposed desert tortoise ACECs, and the area covered by the Las Vegas Valley programmatic consultation. The BLM proposes to authorize activities within the programmatic area that may result in loss of tortoises or their habitat through surface disturbance, land disposal, and fencing, for a period of 5 years. The total area covered by this programmatic biological opinion is approximately 2,636,600 acres, which includes approximately 263,900 acres of BLM-withdrawn lands in Clark County. This programmatic consultation is limited to activities which may affect up to 240 acres per project, and a cumulative total of 10,000 acres, of desert tortoise habitat excluding land exchanges and sales. Only land disposals by sale or exchange within Clark County may be covered under this consultation up to a cumulative total of 14,637 acres. Therefore, a maximum total of 24,637 acres of desert tortoise habitat may be affected by the proposed programmatic activities. The BLM collects a remuneration fee of $623 per acre of disturbance of desert tortoise habitat, as indexed for inflation.

File No. 1-5-98-F-053. On June 18, 1998, the Service issued a programmatic biological opinion to the BLM for implementation of the Las Vegas RMP. The BLM collects a remuneration fee of $623 per acre of disturbance of desert tortoise habitat, as indexed for inflation. The project area for this consultation covers all lands managed by the BLM's Las Vegas Field Office, including desert tortoise critical habitat, proposed desert tortoise ACECs, and BLM-withdrawn land. The Las Vegas Field Office designated approximately 648 square miles of tortoise habitat as desert tortoise ACEC in the Northeastern Mojave RU, and approximately 514 square miles of tortoise habitat as desert tortoise ACEC in the East Mojave RU, through the final RMP. As identified in the RMP, the BLM would manage 743,209 acres of desert tortoise habitat within four tortoise ACECs for desert tortoise recovery. To accomplish recovery of the desert tortoise in the Northeastern and Eastern Mojave RUs, the Las Vegas Field Office will implement appropriate management actions in desert tortoise ACECs through the RMP which includes:

1. Manage for zero wild horses and burros within desert tortoise ACECs.

2. Limit utility corridors to 3,000 feet in width, or less.

3. Do not authorize new landfills or military maneuvers.

4. Require reclamation for activities which result in loss or degradation of tortoise habitat, with habitat to be reclaimed so that pre-disturbance condition can be reached within a reasonable time frame.

5. Limit all motorized and mechanized vehicles to designated roads and trails within ACECs and existing roads, trails, and defined dry washes outside ACECs.

6. Allow non-speed OHV events within ACECs, subject to restrictions and monitoring determinations.

7. Prohibit OHV speed events, mountain bike races, horse endurance rides, four-wheel hill climbs, mini-events, publicity rides, high-speed testing, and similar speed based events.

8. Within ACECs, do not allow commercial collection of flora. Only allow commercial collection of fauna within ACECs upon completion of a scientifically credible study that demonstrates commercial collection of fauna does not adversely impact affected species or their habitat. This action will not affect hunting or trapping, and casual collection as permitted by the State.

File No. 1-5-99-F-450. On March 3, 2000, the Service issued a programmatic biological opinion to the Bureau for implementation of the Caliente Management Framework Plan (CMFP). The Bureau collects a remuneration fee of $623 per acre of disturbance of desert tortoise habitat, as indexed for inflation. The planning area for this consultation covers all desert tortoise habitat managed by the Bureau's Ely Field Office and Caliente Field Station within the Ely District. The planning area comprises approximately 754,600 acres of desert tortoise habitat, including 244,900 acres of designated desert tortoise critical habitat. The Bureau's Ely Field Office will implement management actions described in the biological opinion including multiple-use activities. The CMFP was developed to assist in the recovery and delisting of the Mojave population of desert tortoise in the NEMRU. The CMFP designated three ACECs with a total acreage of approximately 212,500 acres (332 square miles) to be managed primarily for recovery of the desert tortoise.

Implementation of actions by the Ely Field Office which may affect desert tortoise include: Livestock grazing; wild horse and burro management; land disposal and acquisition; rights-of-way management; management of recreational activities including OHV use; minerals management; fire management; and public transportation and access. These actions may result in loss of tortoises or their habitat through programmatic activities over a 10-year period.

Habitat Conservation Plans Completed in Nevada

On May 23, 1991, the Service issued a biological opinion on the issuance of incidental take permit PRT-756260 (File No. 1-5-91-FW-40) under section 10(a)(1)(B) of the Act. The Service concluded that incidental take of 3,710 desert tortoises on up to 22,352 acres of habitat within the Las Vegas Valley and Boulder City in Clark County, Nevada, was not likely to jeopardize the continued existence of the desert tortoise. The permit application was accompanied by the *Short-Term Habitat Conservation Plan for the Desert Tortoise in the Las Vegas Valley, Clark County, Nevada* (Regional Environmental Consultants 1991) (short-term HCP) and an implementation agreement that identified specific measures to minimize and mitigate the effects of the action on desert tortoises.

On July 29, 1994, the Service issued a non-jeopardy biological opinion on the issuance of an amendment to incidental take permit PRT-756260 (File No. 1-5-94-FW-237) to extend the expiration date of the existing permit by 1 year (to July 31, 1995) and include an additional disturbance of 8,000 acres of desert tortoise habitat within the existing permit area. The amendment did not authorize an increase in the number of desert tortoises allowed to be taken under the existing permit. Additional measures to minimize and mitigate the effects of the amendment were also identified. Approximately 1,300 desert tortoises were taken under the authority of PRT-756260, as amended. In addition, during the short-term HCP, as amended, approximately 541,000 acres of desert tortoise habitat have been conserved in Clark County on lands administered by the BLM and the National Park Service.

On February 10, 1995, the Service issued an incidental take permit (PRT-776604) to Nye County for development and operation of a landfill near Pahrump, Nevada. The permit authorized take of 20 desert tortoises and loss of 80 acres of tortoise habitat as a result of the landfill for the next 30 years. Over the term of the permit, Nye County shall transfer up to a total of $25,920 into a desert tortoise trust fund as mitigation for the alteration of up to 80 acres of suitable desert tortoise habitat in the project area. These funds shall be used for the purchase, installation, and maintenance of cautionary tortoise road signs. Surplus funds will be used for public education on the Mojave desert and its inhabitants, including the desert tortoise.

On July 11, 1995, the Service issued an incidental take permit (PRT-801045) to Clark County, Nevada, including cities within the county and the Nevada Department of Transportation (NDOT), under the authority of section 10(a)(1)(B) of the Act. The permit became effective August 1, 1995, and allowed the "incidental take" of desert tortoises for a period of 30 years on 111,000 acres of non-Federal land in Clark County, and approximately 2,900 acres associated with NDOT activities in Clark, Lincoln, Esmeralda, Mineral, and Nye Counties, Nevada. The *Clark County Desert Conservation Plan* (CCDCP) (Regional Environmental Consultants 1995), served as the permitees' habitat conservation plan and detailed their proposed measures to minimize, monitor, and mitigate the effects of the proposed take on the desert tortoise. The permittees imposed, and NDOT paid, a fee of $550 per acre of habitat disturbance to fund these measures. The permittees expended approximately $1.65 million per year to minimize and mitigate the potential loss of desert tortoise habitat. The majority of these funds were used to implement minimization and mitigation measures, such as increased law enforcement; construction of highway barriers; road designation, signing, closure, and rehabilitation; and tortoise inventory and monitoring within the lands initially conserved during the short-term HCP and other areas being managed for tortoise recovery (e.g., ACECs or DWMAs). The benefit to the species, as provided by the CCDCP, substantially minimized and mitigated those effects which occurred through development within the permit area and aided in recovery of the desert tortoise.

On November 22, 2000, the Service issued an incidental take permit (TE-034927-0) to Clark County, Nevada, including cities within the county and the NDOT, under the authority of section 10(a)(1)(B) of the Act. The permit supercedes the incidental take permit for the CCDCP. The new permit allows the "incidental take" of the federally threatened desert tortoise, the federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*), and 76 currently unlisted species for a period of 30 years on 145,000 acres of non-Federal land in Clark County, and within NDOT rights-of-way, south of the 38th parallel in Nevada. The *Clark County Multiple Species Habitat Conservation Plan and Environmental Impact Statement* (MSHCP) (Clark County and Service 2000), serves as the permitees' habitat conservation plan and details their proposed measures to minimize, monitor, and mitigate the effects covered activities on the 78 species. In addition to measures specified in the MSHCP and its implementing agreement, the permittees shall comply with the special terms and conditions of the permit and measures stated in sections 3C and 3D of the CCDCP, which were incorporated by reference into the MSHCP and incidental take permit.

Yucca Mountain does not include private land and occurs in Nye County, therefore the project area occurs outside Clark County's incidental take permit areas for the CCDCP and MSHCP.

Effects of the Proposed Action on the Listed Species

Implementation of the proposed action would result in the loss of up to 1,643 acres of low-density desert tortoise habitat. Increased human use and development of the desert often result in more human interactions with the desert tortoise and its habitat. Extensive disturbance may result in dispersal of tortoises into surrounding areas which are poor to very poor habitat (Karl 1989). Overall, desert tortoise habitats most susceptible to negative impacts are those at the interfaces between developed lands and open desert. Habitat fragmentation associated with development is a major contributor to population declines throughout the range of the tortoise (Berry and Burge 1984). Even near small settlements (e.g., Mercury) and isolated residences the same factors are present, and the cumulative impacts can spread in a radius of several miles from such areas. For example, domestic dogs can be found digging up and killing desert tortoises several miles from home (Service 1994).

Disturbance of desert tortoise habitat during construction of facilities, excavation of trenches, and creation of drill pads are the most obvious effects to desert tortoise. Desert tortoises may be buried in their burrows as a result of road construction and maintenance, killed or injured by project vehicles, drowned by water discharges into washes, trapped or injured by falling into open holes or trenches, or captured and displaced out of harm's way. Additional harassment may occur from increased levels of human activity, noise, and ground vibrations produced by vehicles and heavy equipment (Bondello 1976; Bondello et al. 1979). Desert tortoises may be captured by workers for use as pets. Ground vibrations can cause desert tortoises to emerge from their burrows; slapping the ground several times within a few feet of a desert tortoise burrow entrance will often cause a desert tortoise to emerge (Medica et al. 1986). The measures proposed by DOE to implement a tortoise education program, conduct preactivity and clearance surveys, impose speed limits, and cease activities that threaten a tortoise until the tortoise moves or is moved out of harm's way should minimize these effects.

Yucca Mountain occurs within a restricted access area which prevents tortoises from being collected or harassed by the public. The release of captive animals which are ill may contribute to the spread of URTD or other diseases in wild populations (Jacobson et al. 1995; Jacobson and Gaskin 1990). Because Yucca Mountain is an isolated and restricted access area, the potential introduction of disease to tortoises in the area through release of captive desert tortoises by the public is unlikely.

A survey of approximately 54 miles of electrical transmission lines in southern Nevada produced the remains of 78 juvenile tortoises which were found beneath 23 towers (McCullough Ecological Systems 1995). Ravens use power transmission towers and other man-made structures for perches to locate small, slow-moving hatchling and juvenile tortoises. Natural predation in undisturbed, healthy ecosystems is generally not an issue of concern. However, predation rates may be altered when natural habitats are disturbed or modified. Construction of artificial raven perch and nest sites (e.g., power transmission lines) may increase raven predation of desert tortoises. Roads may provide linear open areas that make tortoises more visible to avian predators. Common raven populations in the California deserts have increased ten-fold from 1968 to 1992 in response to expanding human use of the desert (Boarman and Berry 1995). Because ravens make frequent use of food, water, and nest site subsidies provided by humans, their population increases can be tied to this increase in food and water sources, such as landfills and septic ponds (Boarman 1992; Service 1994). Ravens may be attracted to landfills or project sites if trash is accessible by scavengers (Berry 1985; BLM 1990). Considering that ravens were very scarce in this area prior to 1940, it is assumed that the current level of raven predation on juvenile desert tortoises is an unnatural occurrence (BLM 1990).

Beginning in August 1991 and continuing for 32 months, DOE initiated a raven abundance and monitoring program. During the program, project biologists determined that there was no change in the difference between the number of ravens observed between pre- and post-disturbance (Holt and Mueller 1994). No tortoise carcasses were observed under utility poles or raven nest sites. Because ravens occur at Yucca Mountain and potentially may prey on small tortoises, DOE proposes to continue to implement a litter-control program and manage landfills in a manner which minimizes potential attraction of ravens to the Yucca Mountain.

Desert tortoises will continue to be threatened by roads and vehicles on the project site and access roads. Data from permanent study plots in California show that tortoise densities decreased significantly with increasing mileage of linear disturbances (e.g., roads), increasing numbers of human visitors, and increasing percentages of introduced annual plants (Berry 1992). The density of roads, routes, trails, and ways in desert tortoise habitat has a direct effect on mortality rates and losses of tortoises. Access allows people to penetrate into remote, undisturbed parts of the desert, which contributes to tortoise mortality and habitat loss or degradation (Service 1994). During 1991-1996, four (4) tortoises were reported killed on NTS roads. Movement of tortoises out of imminent danger on roads as authorized by previous biological opinions for the project site and NTS should minimize injury and mortality of tortoises.

Implementation of activities as described in the Plan may result in the long-term disturbance of an additional 1,643 acres of desert tortoise habitat beyond prior project activities. The Service believes that no more than fifteen (15) desert tortoises may be incidentally killed or injured during the proposed action, and up to sixty (60) tortoises captured/displaced as a result of the proposed project.

The Service has determined that the level of effect described herein will not reduce appreciably the likelihood of survival and recovery of the Mojave population of the desert tortoise in the wild or diminish the value of critical habitat both for survival and recovery of the desert tortoise because:

(1) The proposed project area does not occur within any areas recommended for recovery of the desert tortoise or areas designated as critical habitat;

(2) rehabilitation and revegetation of disturbed sites will minimize many of the long-term effects of the proposed project on the desert tortoise;

(3) DOE has made a substantial investment of resources to conserve the desert tortoise at Yucca Mountain. With proper management and continued conservation, desert tortoise populations at Yucca Mountain will remain viable; and;

(4) the project area occurs within the Northeastern RU in Nye County, Nevada. Project activities should not result in a substantial loss of the tortoises within this RU when total desert tortoise population numbers and geographical extent are considered.

Cumulative Effects

Cumulative effects are those effects of future non-Federal (State, local government, or private) activities that are reasonably certain to occur in the project area considered in this biological opinion. Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the Act.

The project area occurs on public land with access restrictions in Nye County. Any future actions on these lands, including Federal transportation rights-of-way and funding in support of the proposed project, will be subject to consultation under section 7 of the Act.

Conclusion

After reviewing the current status of the desert tortoise, the environmental baseline for the project area, the effects of the proposed action and the cumulative effects, it is the Service's biological opinion that construction, operation and monitoring, and closure of a geologic repository at Yucca Mountain is not likely to jeopardize the continued existence of the threatened Mojave population of the desert tortoise. These actions do not affect any area designated as critical habitat; therefore, no destruction or adverse modification of that habitat is anticipated.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act, as amended, prohibits take (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or attempt to engage in any such conduct) of listed species of fish or wildlife without a special exemption. "Harm" is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing behavioral patterns such as breeding, feeding, or sheltering (50 CFR § 17.3). "Harass" is defined as actions that create the likelihood of injury to listed species to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering (50 CFR § 17.3). Incidental take is any take of listed animal species that results from, but is not the purpose of, carrying out an otherwise lawful activity conducted by the Federal agency or applicant. Under the terms of sections 7(b)(4) and 7(o)(2) of the Act, taking that is incidental to and not intended as part of the agency action is not considered a prohibited taking provided that such taking is in compliance with the terms and conditions of this incidental take statement.

The Service hereby incorporates by reference DOE's six proposed measures from the *Description of the Proposed Action* into this incidental take statement as part of these terms and conditions. The following terms and conditions: (1) Restate measures proposed by DOE, (2) modify the measures proposed by DOE, or (3) specify additional measures considered necessary by the Service.. Where these terms and conditions vary from or contradict the measures proposed under the *Description of the Proposed Action*, specifications in these terms and conditions shall apply. The measures described below are nondiscretionary and must be implemented by DOE so that they become binding conditions of any project, contract, grant, or permit issued by DOE, as appropriate, in order for the exemption in section 7(o)(2) to apply.

DOE has a continuing duty to regulate the activity that is covered by this incidental take statement. If DOE fails to adhere to the terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, and/or fails to retain oversight to ensure compliance with these terms and conditions, the protective coverage of section 7(o)(2) may lapse.

Amount of Take

Based on the analysis of impacts provided above, measures proposed by DOE, and anticipated project duration, the Service anticipates that the following take could occur as a result of the proposed action:

1. Fifteen (15) desert tortoises may be accidentally injured or killed onsite during project-related activities as a result of the proposed action. An unknown number of desert tortoises may be killed or injured on project-related roads, however the Service anticipates that fewer than five tortoises per year would be killed on injured on these roads.

2. All desert tortoises encountered within the project area or roads associated with the project may be taken by capture and movement out of harm's way; the Service estimates that no more than sixty (60) desert tortoise will we captured and moved during the project.

3. An unknown number of desert tortoises may be taken in the form of indirect mortality through predation by ravens drawn to the project area.

4. An unknown number of desert tortoise eggs and non-emerged hatchlings may be moved or incidentally destroyed as a result of the project activities.

5. An unknown number of desert tortoises may be taken indirectly in the form of harm or harassment through increased noise associated with operation of heavy equipment.

A total of 1,643 acres of desert tortoise habitat may be destroyed as a result of the proposed action, in addition to the 375 acres disturbed under the previous biological opinions (File Nos. 1-5-90-F-6 and 1-5-96-F-307R).

Effect of the Take

In the accompanying biological opinion, the Service determined that this level of anticipated take is not likely to result in jeopardy to the species or destruction or adverse modification of critical habitat.

Reasonable and Prudent Measures

The Service believes that the following reasonable and prudent measures are necessary and appropriate to minimize take of desert tortoise:

1. Measures shall be taken to minimize take of desert tortoises due to project-related activities and operation of heavy equipment.

2. Measures shall be taken to minimize entrapment of desert tortoises in open trenches.

3. Measures shall be taken to minimize predation on tortoises by ravens drawn to project areas.

4. Measures shall be taken to minimize destruction of desert tortoise habitat, such as soil compaction, erosion, or crushed vegetation, due to project-related activities.

5. Measures shall be taken to ensure compliance with the reasonable and prudent measures, terms and conditions, reporting requirements, and reinitiation requirements contained in this biological opinion.

Terms and Conditions

In order to be exempt from the prohibitions of section 9 of the Act, DOE must fully comply with the following terms and conditions, which implement the reasonable and prudent measures described above.

1. To implement Reasonable and Prudent Measure Number 1, DOE shall fully implement the following measures:

    a. Clearance surveys will be conducted by qualified biologists prior to clearing of vegetation at previously undisturbed sites if new disturbances are larger than 5 acres or records indicate tortoises may occur in the area to be disturbed. If the project activity can occur in an adjacent area where no tortoises or sign are present, the proposed activity shall be moved. If no suitable site is totally free of tortoises or tortoise sign, the qualified biologist shall determine which site would cause the least impact to tortoises and their habitat.

In accordance with *Procedures for Endangered Species Act Compliance for the Mojave Desert Tortoise* (Service 1992), a qualified desert tortoise biologist shall possess a bachelor's degree in biology, ecology, wildlife biology, herpetology, or closely related fields. The biologist must have demonstrated prior field experience using accepted resource agency techniques to survey for desert tortoises and tortoise sign. In addition, the biologist shall have the ability to recognize and accurately record survey results.

b. Clearance surveys will be conducted either the day prior to, or the day of, any surface-disturbing activity during the tortoise activity season (February 16 through November 14). Based on the results of the hibernation study conducted at the Yucca Mountain Site Characterization Project (Rautenstrauch et al. 1997), the Service anticipates that most tortoises will be in hibernacula during the inactive season and will remain there during a 7-day period between survey and activity. Therefore, clearance surveys will be conducted within 7 days prior to any surface-disturbing activity during the hibernation period (November 15 through February 15). Qualified desert tortoise biologists will search areas to be cleared using techniques providing 100-percent coverage of all areas to be disturbed, as described in Term and Condition 1.a. above. If tortoises or eggs are found during clearance surveys, they will be moved out of harm's way following Service guidelines (Desert Tortoise Council 1994, revised 1999). All tortoise burrows, and other animal burrows that may be used by tortoises, that are found during clearance surveys will be conspicuously flagged and avoided by at least 30 feet.

c. If a burrow cannot be avoided, it will be inspected to determine the presence of tortoises or tortoise nests. If unoccupied, the burrow will be collapsed to prevent tortoise entry. All unavoidable burrows containing tortoise eggs or tortoises will be excavated by hand to remove the tortoise and/or eggs. Tortoise eggs and tortoises in harm's way will be removed and relocated by qualified biologists and handled according to desert tortoise handling procedures approved by the Service. (Currently, the approved procedures are in: Desert Tortoise Council 1994, revised 1999).

d. If removed from a burrow, the tortoise will be placed in the shade of a shrub or in an existing, similar, unoccupied tortoise burrow that is approximately the same size, depth, and orientation as the original burrow. Desert tortoises moved during the tortoise inactive season (i.e., November 15 through February 15), or those considered by the qualified desert tortoise biologist to be in estivation or brumation, regardless of date, must be placed into an adequate burrow. If suitable, unoccupied burrow (i.e., similar in size, depth, and orientation as the original burrow) is not available, one will be constructed utilizing the protocol for burrow construction in section B.5.f of the Service-approved guidelines (Desert Tortoise Council 1994, revised 1999).

e. Project activities that may endanger a tortoise will cease if a tortoise is found on a project site. Project activities will resume after the biologist removes the tortoise from danger or after the tortoise has moved to a safe area.

f. A tortoise biologist or environmental monitor (in place of a desert tortoise biologist) will be onsite during all phases of each construction activity to ensure construction activities are in compliance with this biological opinion and that desert tortoises are not inadvertently harmed.

The environmental monitor may be the project foreman or supervisor who will be responsible for: (1) Enforcing the litter-control program; (2) ensuring that tortoise-proof fences are maintained where applicable; (3) ensuring that desert tortoise habitat disturbance is restricted to authorized areas; (4) ensuring that all equipment and materials are stored within the boundaries of the construction zone or within the boundaries of previously disturbed areas; (5) ensuring that all vehicles associated with construction activities are using existing graded or paved roads or are within the proposed construction zones; (6) ensuring that open trenches or other excavations are inspected in accordance with term and condition 2 of this biological opinion; (7) ensuring that speed limits are observed; and (8) ensuring compliance with the terms and conditions of this biological opinion. An environmental monitor is not authorized to handle tortoises, which will only be done by a qualified desert tortoise biologist.

g. Vehicles will not be driven off existing roads in non-emergency situations unless authorized by DOE. During the tortoise active season (February 15 through November 15) the proposed vehicle path will be cleared of tortoises immediately prior to off-road travel. During the tortoise inactive season, the proposed vehicle path will be flagged and cleared of tortoises within 7 days prior to off-road travel.

h. All vehicles will be driven at speeds within the posted speed limits on existing roads, and will not exceed 25 miles per hour on unposted roads.

I. DOE will continue to present a tortoise education program to all workers and employees working on the project site. This will include information on the life history of the desert tortoise, legal protection for desert tortoises, penalties for violations of Federal and State laws, general tortoise activity patterns, reporting requirements, measures to protect tortoises, and personal measures employees can take to promote the conservation of desert tortoises. The definition of "take" will also be explained. All questions on desert tortoises or actions which may affect tortoise will be answered accurately by the instructor or a qualified tortoise biologist. All DOE and contractor personnel working on the project at Yucca Mountain will complete the DOE tortoise education program.

The education program shall instruct attendees that the definition of "take" includes capture. Therefore, any unauthorized person who picks up a desert tortoise or restricts the animal's ability to move freely, could be found guilty of illegal "take" unless done in accordance with this biological opinion. The same applies for any individual if the authorized level of incidental take has been reached or exceeded. Any action taken to harm, harass, pursue, hunt, shoot, wound, kill, collect, capture, or trap a tortoise, or attempt to conduct any of these activities constitutes take.

Incidental take occurring which is consistent with the *Incidental Take Statement* of this biological opinion would be legal; for example, moving a tortoise out of the path of an approaching vehicle if the tortoise is observed in the road within the project area. However, the tortoise may not be moved if it is not in imminent danger and will leave the road of its own accord. If a tortoise must be moved off a road to avoid imminent injury or mortality, the tortoise must be moved in the same direction of travel. The tortoise shall be picked up gently with two hands, kept level, and carried close to the ground. The tortoise shall be placed in the shade of a shrub approximately 25 feet from the road edge.

j. Marking or radiotelemetry of desert tortoises is not authorized under this biological opinion. Tortoises shall be purposefully moved only by qualified tortoise biologists, solely for the purpose of moving them out of harm's way, with the exception identified in 1.i. above.

2. To implement Reasonable and Prudent Measure Number 2, DOE shall fully implement the following measures:

a. During the tortoise active season (February 16 through November 14), all trenches and other excavations with side slopes steeper than 1-foot rise to 3-foot length shall be immediately backfilled prior to being left unattended, or: (1) Fenced with tortoise-proof fencing; (2) covered with tortoise-proof fencing; (3) covered with plywood or similar material; or (4) constructed with escape ramps at each end of the trench and every 1,000 feet, at a minimum. All coverings and fences shall have zero ground clearance. If alternative 4 is selected, the trench or other excavation will be inspected periodically and following periods of substantial rainfall to ensure structural integrity and that escape ramps are functional.

b. An open trench or other excavation as described in 2.a. shall be inspected for entrapped animals immediately prior to backfilling.

c. If at any time a tortoise is discovered within a trench, all activity associated with that trench shall cease until a qualified biologist has removed the tortoise in accordance with Service-approved guidelines (Desert Tortoise Council 1994, revised 1999).

3. To implement Reasonable and Prudent Measure Number 3, DOE shall fully implement the following measure:

DOE will implement a litter-control program that will include the use of covered, raven-proof trash receptacles; disposal of edible trash in trash receptacles following the end of each work day; and disposal of trash in a designated sanitary landfill at the end of each week or when nearly full. Material placed in a sanitary landfill will be covered often enough to prevent ravens and other predators from feeding in the area.

4. To implement Reasonable and Prudent Measure Number 4, DOE shall fully implement the following measure:

Project areas no longer required by the project will be revegetated in accordance with the *Reclamation Implementation Plan* (Reclamation Plan) (DOE 2001c), RSMP (DOE 1998) developed for the Yucca Mountain Site Characterization Project, and recommendations made by Rakestraw et al. (1995). Site-specific plans will be developed for each site to be rehabilitated and shall conform with the Reclamation Plan and RSMP. Only native perennial vegetation and annual plants, including forage species of desert tortoises will be used on the project site. DOE shall conduct a field survey at each site and develop site-specific reclamation plans for surface-disturbing projects within desert tortoise habitat. These plans may include specifications for contouring, relieving soil compaction, treating and/or spreading topsoil, and planting. In addition, these plans will describe in specific detail how disturbed sites will be rehabilitated using reasonable state-of-the-art techniques.

5. To implement Reasonable and Prudent Measure Number 5, DOE shall fully implement the following measures:

   a. Prior to handling any desert tortoise, carcass, or egg, appropriate State permits will be acquired from the Nevada Division of Wildlife.

   b. DOE will designate a field contact representative for each project, which may also serve as the environmental monitor, if appropriate. The field representative will be responsible for overseeing compliance with protective stipulations for the desert tortoise and for coordinating compliance with the terms and conditions of this biological opinion. The field representative will have the authority to halt activities of construction equipment which may be in violation of the stipulations.

   c. DOE will keep an up-to-date log of all actions taken under this consultation, including acreage affected, habitat rehabilitation actions completed, number of desert tortoises taken and by what means (e.g., injured, killed, captured and displaced, or found in trenches or pits). DOE will provide the above information to the Service's Las Vegas Office on February 28 of every year during which activities occur under this biological opinion. The first annual report will be due February 28, 2002. Information provided in the report shall state cumulative totals, as well as totals for the report year.

The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize the anticipated incidental take that may result from the proposed action. With implementation of these measures, the Service believes that no more than fifteen (15) desert tortoises may be incidentally killed or injured, and up to sixty (60) desert tortoises captured and displaced during the proposed project. An additional 1,643 acres of desert tortoise habitat may be disturbed as a result of project activities.

If, during the course of the action, the level of incidental take or loss of habitat identified is exceeded, reinitiation of consultation will be required. DOE must immediately provide an explanation of the causes of the taking and review with the Service the need for possible modification of the reasonable and prudent measures.

Reporting Requirements

Upon locating a dead or injured endangered or threatened species, initial notification must be made to the Service's Division of Law Enforcement in Las Vegas, Nevada, at (702) 388-6380. Care should be taken in handling sick or injured desert tortoises to ensure effective treatment and care or the handling of dead specimens to preserve biological material in the best possible state for later analysis of cause of death. In conjunction with the care of sick or injured desert tortoises or preservation of biological materials from a dead animal, the finder has the responsibility to carry out instructions provided by the Service's Division of Law Enforcement to ensure that evidence intrinsic to the specimen is not unnecessarily disturbed. All deaths, injuries, and illnesses of desert tortoises, whether associated with project activities or not, will be summarized in the annual report.

The following actions should be taken for injured or dead tortoises if directed by the Service's Division of Law Enforcement:

> Injured desert tortoises shall be delivered to any qualified veterinarian for appropriate treatment or disposal. Dead desert tortoises suitable for preparation as museum specimens shall be frozen immediately and provided to an institution holding appropriate Federal and State permits per their instructions. Should no institutions want the desert tortoise specimens, or if it is determined that they are too damaged (crushed, spoiled, etc.) for preparation as a museum specimen, then they may be buried away from the project area or cremated, upon authorization by the Service's Division of Law Enforcement. DOE, or the project proponent, shall bear the cost of any required treatment of injured desert tortoises, euthanasia of sick desert tortoises, or cremation of dead desert tortoises. Should sick or injured desert tortoises be treated by a veterinarian and survive, they may be transferred as directed by the Service.

Conservation Recommendations

Section 7(a)(1) of the Act directs Federal agencies to use their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information.

> *The Service recommends that DOE continue to consider important desert tortoise habitat at Yucca Mountain during the development and transportation phases of the project.*

In order for the Service to be kept informed of actions that either minimize or avoid adverse effects or that benefit listed species or their habitats, the Service requests notification of the implementation of any conservation recommendations.

Reinitiation Notice

This concludes formal consultation on the actions outlined in your April 24, 2000, request. As required by 50 CFR § 402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over an action has been retained (or is authorized by law) and if: (1) The amount or extent of incidental take is exceeded; (2) new information reveals effects of the agency action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion (e.g., a substantial number of tortoises are killed or injured on established access roads, particularly along a specific road section); (3) the agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in this opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action. In instances where the amount or extent of incidental take is exceeded, any operations causing such take must cease pending reinitiation.

If we can be of any further assistance, please contact Michael Burroughs, in the Southern Nevada Field Office, at (702) 647-5230.

Sincerely,

Michael Burroughs

for Robert D. Williams
Field Supervisor

cc:
Administrator, Nevada Division of Wildlife, Reno, Nevada
Manager, Nevada Division of Wildlife, Las Vegas, Nevada
Deputy Director, Environmental Management, Department of the Air Force, Nellis AFB, Nevada
Deputy State Director, Resources, Land Use and Planning, Bureau of Land Management, Reno, Nevada
Project Leader, Desert National Wildlife Refuge Complex, Fish and Wildlife Service, Las Vegas, Nevada
Assistant Regional Director, Ecological Services, Fish and Wildlife Service, Portland, Oregon
Senior Resident Agent, Division of Law Enforcement, Fish and Wildlife Service, Boise, Idaho

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CONVERSIONS

METRIC TO ENGLISH			ENGLISH TO METRIC		
Multiply	**by**	**To get**	**Multiply**	**by**	**To get**
Area					
Square meters	10.764	Square feet	Square feet	0.092903	Square meters
Square kilometers	247.1	Acres	Acres	0.0040469	Square kilometers
Square kilometers	0.3861	Square miles	Square miles	2.59	Square kilometers
Concentration					
Kilograms/sq. meter	0.16667	Tons/acre	Tons/acre	0.5999	Kilograms/sq. meter
Milligrams/liter	1[a]	Parts/million	Parts/million	1[a]	Milligrams/liter
Micrograms/liter	1[a]	Parts/billion	Parts/billion	1[a]	Micrograms/liter
Micrograms/cu. meter	1[a]	Parts/trillion	Parts/trillion	1[a]	Micrograms/cu. meter
Density					
Grams/cu. cm	62.428	Pounds/cu. ft.	Pounds/cu. ft.	0.016018	Grams/cu. cm
Grams/cu. meter	0.0000624	Pounds/cu. ft.	Pounds/cu. ft.	16,025.6	Grams/cu. meter
Length					
Centimeters	0.3937	Inches	Inches	2.54	Centimeters
Meters	3.2808	Feet	Feet	0.3048	Meters
Kilometers	0.62137	Miles	Miles	1.6093	Kilometers
Temperature					
Absolute					
Degrees C + 17.78	1.8	Degrees F	Degrees F – 32	0.55556	Degrees C
Relative					
Degrees C	1.8	Degrees F	Degrees F	0.55556	Degrees C
Velocity/Rate					
Cu. meters/second	2118.9	Cu. feet/minute	Cu. feet/minute	0.00047195	Cu. meters/second
Grams/second	7.9366	Pounds/hour	Pounds/hour	0.126	Grams/second
Meters/second	2.237	Miles/hour	Miles/hour	0.44704	Meters/second
Volume					
Liters	0.26418	Gallons	Gallons	3.78533	Liters
Liters	0.035316	Cubic feet	Cubic feet	28.316	Liters
Liters	0.001308	Cubic yards	Cubic yards	764.54	Liters
Cubic meters	264.17	Gallons	Gallons	0.0037854	Cubic meters
Cubic meters	35.314	Cubic feet	Cubic feet	0.028317	Cubic meters
Cubic meters	1.3079	Cubic yards	Cubic yards	0.76456	Cubic meters
Cubic meters	0.0008107	Acre-feet	Acre-feet	1233.49	Cubic meters
Weight/Mass					
Grams	0.035274	Ounces	Ounces	28.35	Grams
Kilograms	2.2046	Pounds	Pounds	0.45359	Kilograms
Kilograms	0.0011023	Tons (short)	Tons (short)	907.18	Kilograms
Metric tons	1.1023	Tons (short)	Tons (short)	0.90718	Metric tons
ENGLISH TO ENGLISH					
Acre-feet	325,850.7	Gallons	Gallons	0.000003046	Acre-feet
Acres	43,560	Square feet	Square feet	0.000022957	Acres
Square miles	640	Acres	Acres	0.0015625	Square miles

a. This conversion is only valid for concentrations of contaminants (or other materials) in water.

METRIC PREFIXES

Prefix	Symbol	Multiplication factor
exa-	E	1,000,000,000,000,000,000 = 10^{18}
peta-	P	1,000,000,000,000,000 = 10^{15}
tera-	T	1,000,000,000,000 = 10^{12}
giga-	G	1,000,000,000 = 10^{9}
mega-	M	1,000,000 = 10^{6}
kilo-	k	1,000 = 10^{3}
deca-	D	10 = 10^{1}
deci-	d	0.1 = 10^{-1}
centi-	c	0.01 = 10^{-2}
milli-	m	0.001 = 10^{-3}
micro-	µ	0.000 001 = 10^{-6}
nano-	n	0.000 000 001 = 10^{-9}
pico-	p	0.000 000 000 001 = 10^{-12}