Appendix G
Intersite Transportation

This appendix supplements Section 4.4. It describes the methodology used for intersite transportation risk analysis and provides estimated health risks from the transport of materials, historical shipment data for the affected sites, and other supporting documentation. Intrasite transportation of pits between Zone 4 and Zone 12 at Pantex to support storage of RFETS pits for the Preferred Alternative is described in Appendix Q.

G.1 TRANSPORTATION RISK ANALYSIS METHODOLOGY

G.1.1 TRUCK AND RAIL TRANSPORTATION RISK

This assessment addresses the intersite transport of plutonium (Pu), highly enriched uranium (HEU), cesium, Pu oxide (PuO_2), uranium oxide, mixed oxide fuel (MOX), low-level waste (LLW), transuranic waste, and immobilized material. Pu, including MOX fuel, and HEU would be transported in truckload shipments by safe secure trailer (SST). The other materials would be transported by commercial truck, except for immobilized Pu with radionuclides (vitrified glass logs, ceramic disks, or glass-bonded zeolite in canisters), which would be transported to a repository by rail. For overseas shipments, this assessment includes port handling and ocean transport. This assessment compares transportation impacts for the alternatives considered.

For this analysis, the isotopic composition of Pu was assumed to be 93 percent Pu-239, 6 percent Pu-240, and 1 percent other Pu isotopes. The isotopic composition of HEU was assumed to be 93 percent uranium-235. For the other radioactive materials to be transported, the isotopic compositions were estimated based on data provided from the facility designers.

Handling risk involves the loading and unloading of transport vehicles, which was estimated on a per-vehicle (truckload/rail carload) basis. One loading and unloading operation was assumed for each shipment. It was estimated that there would be two cargo handlers and 35 other workers within 50 meters (m) (164 feet [ft]) of the loading/unloading operations. Because of the low speeds, less than 8 kilometers per hour (km/hr) (5 miles per hour [mph]), involved in transferring Pu and uranium between a storage facility and the transport vehicles and because the rigid design standards used for the Type B packagings allow them to withstand an accident (for example, a fork lift puncture), it is extremely unlikely that a Type B package would be breached. The estimated probability of a package being damaged so severely (for example, by forklift puncture, high winds, or tornados) that the inner and outer containers would fail and some fraction of the contents would be dispersed is extremely low (that is, less than 1.0×10^{-12}). However, design-basis and beyond-design-basis accidents with frequencies in the range of 10^{-2} to 10^{-7} are evaluated under facility accidents. Detailed analyses and test results including a puncturing forklift accident which serves as a bounding value, are presented in Section M.5. The risk factor from transferring Pu and HEU between the storage facility and the transport vehicles is so low as to be inconsequential. Therefore, it is unlikely that a worker or member of the public fatality would occur as a result of an accident during the transfer of Pu or HEU. The collective dose due to accident-free radiological exposure to cargo handlers and other workers for each loading operation is estimated to be 0.06 person-roentgen equivalent man (rem) and 0.004 person-rem, respectively. Because the loading would occur onsite in a secure area, there would be no exposure to the public.

For the transportation analysis, materials were assumed to be in shippable forms that have been stabilized and packaged for shipment at the originating site and meet Department of Transportation (DOT), Nuclear Regulatory Commission (NRC), and Department of Energy (DOE) requirements. The health impacts from the transport of materials were estimated using an assumed population distribution along specific routes when sites were known or along an assumed route distribution of 84-percent rural, 15-percent suburban and 1-percent urban for generic sites; average container, truckload, or rail carload of material; and a standard unit of measure

for traffic fatalities (the risk per kilometer). Potential impacts are presented for both accident and accident-free scenarios.

The RADTRAN Version 4 computer code, developed and maintained by Sandia National Laboratories at Albuquerque, NM, was used to estimate health risks in terms of potential total fatalities from the transport of radioactive materials. The RADTRAN code combines user-determined demographic, transportation, packaging, and material factors with health physics data to calculate the expected radiological consequences of accident-free and accident transportation scenarios.

The transportation accident model in RADTRAN assigns accident probabilities to a set of accident categories. For the truck analysis, the eight accident-severity categories defined in NRC's *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes* (NUREG-0170, December 1977) were used. The least severe accident category (Category I) represents low magnitudes of crush force, accident-impact velocity, fire duration, or puncture-impact speed. The most severe category (Category VIII) represents a large crush force, high accident-impact velocity, long fire duration, and high puncture-impact speed, such as an 88-km/hr (55-mph) collision into the side of the vehicle, and a 982 degrees Centigrade (°C) (1,800 degrees Fahrenheit [°F]) fire lasting 1.5 hr to produce a release of the material. The release fractions for Category VIII accidents were conservatively estimated to be 0.1 for the strictly controlled SST shipments and 1.0 for other shipments.

A unit dose per shipment was calculated using RADTRAN for each type of radioactive material to be transported between sites and for each alternative. The distance and fraction of rural, suburban, and urban population for each route was estimated using the INTERSTAT routing code for truck transport and INTERLINE for rail transport. These two routing codes are integrated with the RADTRAN code. For sea transport, the actual distance was used between an East Coast port (hypothetically, the U.S. Army port at Sunny Point, NC) to ports in the United Kingdom and France, 6,297 km (3,400 nautical miles) and 6,112 km (3,300 nautical miles), respectively. For land transport by SST to facilities without a specific site, a potential bounding risk was established for distances of 1,000 kilometers (km) (620 miles [mi]), 2,000 km (1,240 mi), and 4,000 km (2,480 mi), assuming rural, suburban, and urban population distributions of 84, 15, and 1 percent, respectively along the route. Under the European MOX fuel fabrication variant, the impacts from the transport of Pu materials from DOE origins (that is, existing storage, pit disassembly/conversion site, or Pu conversion site) to placement of the material aboard ship, were considered. For the assessment, the representative port was assumed to be at distances of 1,000 km (620 mi); 2,000 km (1,240 mi); or 4,000 km (2,480 mi) from the origin.

The transport index is a regulatory characteristic of a package and is equal to the radiation dose rate in mrem per hour at a distance of 1 m (3.3 ft) from the outside of the package (49 CFR 173.403). The transport index values were estimated to be the maximum allowed by regulatory requirements, as indicated by regulatory checks incorporated in RADTRAN. These regulatory checks limit the product of the number of packages and the transport index (of each package) to a value of about 16. This value was used as a bounding value for evaluating impacts. The quantity of material per package, number of packages per truckload, and number of truckloads (shipments) for the life of the project were based on estimates for each storage and disposition alternative.

To determine the transportation accident and accident-free impacts, the unit dose (the derived radiation dose for each shipment) was converted to a unit risk factor per shipment by multiplying the occupational accident-free dose by 4.0×10^{-4} cancers per person-rem and the public accident and accident-free dose by 5.0×10^{-4} cancers per person-rem (ICRP 1991a:22).

Nonradiological impacts from accident-free (air pollution) and highway accidents were also assessed. Fatalities from potential air pollution were estimated using 1.0×10^{-7} cancer fatalities per urban kilometer. Highway accident fatalities were estimated from national statistics using 1.5×10^{-8} rural, 3.7×10^{-9} suburban, and 2.1×10^{-9} urban for

occupational risks per km, and 5.3×10^{-8} rural, 1.3×10^{-8} suburban, and 7.5×10^{-9} urban for nonoccupational risks per km (SNL 1986a:167). The combined resultant health risks are presented as potential fatalities.

The estimated impacts for each alternative were derived by summing the health effects for the materials to be transported for each transportation segment required by the alternative.

G.1.2 Risk Associated With Port Handling and Global Commons for European Mixed Oxide Fuel Fabrication

For the Existing Light Water Reactor Alternative, MOX fuel could be produced in existing European facilities to meet interim needs, pending availability of a domestic MOX fuel fabrication plant. Therefore, this programmatic environmental impact statement (PEIS) considered transportation impacts at the ports and global commons. The methodologies for the various cases are explained in the following sections.

G.1.2.1 Port Transit and Intermodal Handling Analysis (Accident-Free Conditions)

The materials to be shipped under this action (Pu oxides and fresh MOX fuel assemblies) emit low radiation levels. Consequently, the self-shielding and the shielding afforded by the external walls of the shipping containers are sufficient to reduce the estimated maximum dose rate at 1 m (3.3 ft) from the package to zero for the 6M package (with 2R inner container) and to less than 1.5×10^{-4} millirem/hr for the MO-1 package. [Text deleted.]

G.1.2.2 Port Transit and Intermodal Handling Analysis (Accident Conditions)

For the shipment of Pu oxide from lag storage to an overseas MOX fuel fabrication site and the return shipment of reactor fuel assemblies, (1) material would be transported by SST to or from the selected U.S. port and (2) shipping containers would be transferred between the SST and the ships. The Pu oxide would be contained in 6M-2R, Type B packaging which would be placed in groups of eight or fewer packages in a cargo restraint transporter (CRT) to facilitate loading and securing in the SST. For ship transport, the 6M-2R packagings would be placed in International Standards Organization (ISO) intermodal containers that are compatible with the common handling and securing facilities available. The returning fuel assemblies would be shipped in MO-1 casks that meet Type B certification requirements.

The shipping schedule projects two shipments of Pu oxide per year and a maximum of four shipments of fresh MOX fuel assemblies per year. Facilities for transferring CRTs from the SST to the ISO containers and staging of returning fuel casks unloaded from ships to multiple SST convoys would be available in the immediate port area. Handling and short-term storage in these facilities do not involve significant accident risks apart from the remote possibility of a major fire. All other mishaps that might occur during the shipping, handling, and inspection operations are subsumed in the accident rate per port transit of a ship, which is described in Section G.1.2.3. Transportation risks associated with SST operations are treated separately.

During port transit, loading, and unloading, the occurrence probability of an accident of any type can be assigned from reported statistics. In this analysis, all accidents involving a container breach and fire on a ship are modeled as occurring at pier side. This approach is highly conservative in that it ignores both the high probability of a greater stand-off distance and the fact that transits to ports are typically through low population density areas. Additionally, in the absence of prevailing wind data, the radioactive cloud (plume) is modeled as traveling over the port area and out to a distance of 80 km (50 mi). In reality, the prevailing winds might blow the plume away from populated areas. Without detailed population density data, the accident model treats the port population density as continuing out for the full 80 km (50 mi).

G.1.2.3 Modal Considerations

Maritime accident rate data indicate that the basic accident rate in and near ports is approximately 3.0×10^{-4} per port transit; that is, three accidents per 10,000 port visits (DOE 1991s:22). The conditional occurrence probabilities of each accident severity have been developed as well. A conditional probability is defined as the probability, given that an accident has occurred, that it will be of a certain severity. In order to calculate overall probability of an accident of a particular severity, the base accident probability (accident rate) must be multiplied by the conditional probability. For Type B packages containing the materials contemplated in this action (Pu oxide and fresh MOX fuel assemblies), the highest conditional probability, for an accident resulting in the release of package contents, yields an overall maximum accident probability of 5.0×10^{-9} per port transit (DOE 1996n:D-191; SNL 1995b:3). The resultant overall probability is, therefore, approximately 3.0×10^{-8}/year (yr) (that is, number of accidents per transit multiplied by number of transits per year [six]).

Activities or conditions that affect material release from packages in the event of an accident include, but are not limited to, the following:

- **Container Drops During Intermodal Transfer.** Berths at all ports considered in this action are likely to consist of either concrete aprons constructed on friction pilings driven into the sediment or tamped earth contained within sheet pilings and surfaced with concrete. Both are yielding surfaces, and the water and the deck of a ship are even more yielding than a dock surface. Previous studies have shown that a Type B package can be dropped onto a yielding surface from at least 10 m (30 ft) (as specified for Type B packaging) without sustaining damage (IAEA 1987a:551; SNL 1975a:7,15). Information describing Type B package testing is contained in Section G.5.

  Container drops are infrequent, and such a drop would be considerably less severe than the certification drop test conditions, even if the container was dropped from greater than 10 m (30 ft), because of the yielding nature of the surfaces onto which they might fall. Therefore, container drops during intermodal transfers are not considered a threat to Type B packaging, and they need not be considered further in this analysis. Since truck velocities within the immediate confines of a port are low and container movements are preceded by a port authority police escort vehicle, truck accidents in port also are not considered further. Port accidents that are considered consist mainly of vessel accidents, including accidents in which a moored ship is struck, usually by another ship (SNL 1980a:4-1,4-2).

- **Packaging Response to Thermal Conditions.** The packaging considered for this action is designed to survive the thermal load specified in the Type B packaging certification tests with no release of contents. Total heat input to a package is more important than peak temperature. A fire that meets or exceeds the regulatory fire temperature of 800 °C (1,470 °F) may have no effect whatsoever on the package if it does not engulf the cask (that is, if it does not satisfy the test condition of the entire package being exposed to the fire) and/or if it does not last at least as long as the 30 minutes specified in the regulatory test (NRC 1987b:2-24).

  The likelihood that a shipboard fire will occur in the same location as the cargo is relatively small; many ship fires are confined to engine rooms, galleys, etc., and do not affect cargo areas (SNL 1980a:4-19). Fire-duration is also unlikely to be a factor. Although shipboard fires have been described as burning for days, that is not, by itself, sufficient information to determine whether any particular location as small in volume as a single container is exposed to fire at all, much less "for days." Indeed, shipboard fires are often traveling fires, which progress through a ship during the course of a fire and during which no single location in the fire's path is exposed for a prolonged period of time. Fires involving tanker ships are not directly relevant to conditions onboard container ships; tanker fires are discussed in *Tanker Accident Rates and Expected Consequences in U.S. Ports*

and High Seas Regions (TRB 1985a:164). In a rare historical accident involving the collision of an oil tanker and a cargo ship, conditions onboard the tanker and container ships were quite different (DOT 1975a:1; NTSB 1975a:1).

- **Atmospheric Dispersal.** Atmospheric dispersal is usually the means of spreading any material released during a severe accident beyond the immediate vicinity and into the human environment. Dispersal is affected by the degree of turbulence in the atmosphere, which can vary from unstable (Class A) to extremely stable (Class F). The Pasquill system of atmospheric stability classes is commonly used to describe this variation, although there are other systems (NRC 1983a:2-18). A conservative representation of atmospheric conditions at ports generated by the DIFOUT dispersion code for Class D, which has been used in previous port analyses, was used for this analysis (SNL 1969a:19).

G.1.2.4 Port Handling Impacts

Accident-risk estimates were calculated using the RADTRAN 4 computer code. Overall probabilities for accidents of sufficient severity to release radioactive materials to the environment during a port transit and associated handling were obtained from "Radiological Consequences of Ship Collisions That Might Occur in U.S. Ports During the Shipment of Foreign Research Reactor Spent Nuclear Fuel to the United States in Break-Bulk Freighters." Package releases were modeled in accord with shipment of powdered material of fissile assemblies (taking account of their unirradiated state). Since specific ports have not been identified, population density in the vicinity of a nominal port was set at a mean urban value of 3,861 square kilometers (10,000 square miles), which is very conservative for most U.S. ports. Impacts, calculated in terms of dose risk and latent cancer fatalities, for all shipments in 1 year (2 export; 4 import) are presented in Table G.1.2.4–1 together with the separate export and import risks. The health risks are based on a value of 5.0×10^{-4} fatalities per person-rem for the general public (workers are included with the public for accident conditions).

If any of the alternatives in the reactor category were selected, MOX fuel would have to be fabricated. No decision has been made as to where MOX fuel would be fabricated or to where the fuel would be transported for use. However, if the decision were to make any of the MOX fuel in Europe, DOE would ship Pu by sea through ocean ports and would receive MOX fuel shipped by sea from Europe, again through ocean ports. The selection of which ports, after additional environmental reviews under NEPA, would be part of the larger DOE transportation planning process that would also determine shipment schedules, port or ports of entry and exit, modes of transport to and from the ports, emergency preparedness plans and contacts, and communications strategies based on current capabilities. Because there is uncertainty associated with the future nature of port activities and their capabilities for handling Pu and MOX fuel 10 or more years into the future, no specific ports were analyzed for this PEIS. For determining the distance between a port on the eastern U.S. coast and a port in the Great Britain or France, Sunny Point, NC, was used. The distance between Sunny Point, NC, and the European ports is stated in Section G.1.1.

In selecting transportation routes, including any ports, the safety of the public and security of the cargo are of primary consideration. To ensure these primary considerations are achieved, DOE would evaluate the ports to be used based on a set of criteria that would include adequacy of harbor and dock characteristics to satisfy the Pu container carrying ship requirements; adequacy of facilities for safe receipt, handling, and transhipment of Pu and MOX fuel; overall port security; availability of safe and secure lag storage; adequacy of overland transportation systems from ports to the reactor and from the Pu site(s); availability of a skilled labor force with routine experience in safe and secure handling of hazardous cargo; emergency preparedness status and response capabilities at the port and the nearby communities; quality of intermodal access for truck or rail shipments to and from the port; proximity to the proposed pit disassembly/conversion facility and reactor sites; local restrictions or regulations on movement of hazardous cargo; absence of significant environmental restrictions from the port; and the size of human population at the ports and along transportation routes.

Table G.1.2.4–1. Annual Accident Risks Due to Export of Plutonium Oxide and Import of Mixed Oxide Fuel

	Annual Shipments	Annual Dose-Risk (person-rem)	Health Effect[a]
PuO_2–export	2	3.3	$1.6x10^{-3}$
MOX fuel–import	4	$3.6x10^{-7}$	$1.8x10^{-10}$
Total annual effect		3.3	$1.6x10^{-3}$

[a] Estimated latent cancer fatalities per year.
Source: RADTRAN model results.

The total health risk of $1.6x10^{-3}$ latent cancer fatalities per year is a highly conservative estimate, as the population density surrounding actual ports may be smaller by as much as a factor of 10. Also, one-half of the 6M-2R packages in the particular ship hold impacted during an accident are modeled as being affected in severe accidents; this is considered to be very unlikely. The major reason the risk associated with the PuO_2 shipments is higher than that for the MOX fuel is the physical state of the material, a fine powder, which is 100 percent dispersible upon release. If the PuO_2 is shipped as pellets, as in the case for fuel rods, the annual risk for the PuO_2 shipments is reduced to $1.6x10^{-7}$person-rem or $8.2x10^{-11}$ latent cancer fatalities.

G.1.2.5 Effects on the Global Commons

European MOX fuel fabrication, which could be used on a short-term basis to provide lead test assemblies and other MOX fuel, would option involves the shipment of Pu oxide on an ocean-going vessel to Europe, where it would be fabricated and loaded into MOX fuel assemblies and returned by ship to the United States. The frequency of a severe maritime accident, sufficient to release radioactive materials resulting in catastrophic consequences, is less than $1.0x10^{-6}$/yr. Nevertheless, this discussion addresses concerns that could arise over potential impacts to the global commons from an accident involving the shipment of Pu oxide or MOX fuel.

However unlikely, there is always a potential for maritime accidents during the ocean shipment of Pu and MOX fuel. The severity of maritime accidents ranges from immersion to collision to fire and collision. Accidents in the port egress areas have a greater potential for public consequences than accidents on the open seas because of the proximity to populated areas. Studies performed for recent *National Environmental Policy Act* (NEPA) of 1969 documents conclude that the probability of a maritime accident of sufficient severity to cause significant release of radioactive materials resulting in catastrophic consequences is extremely small, on the order of $1.0x10^{-8}$ per port call (DOE 1993x:A-3) to $1.0x10^{-9}$ per port call (DOE 1996n:D-191). Assuming six shipments per year, the probability of a maritime accident would be in the order of $1.0x10^{-7}$/yr to $1.0x10^{-8}$/yr.

An environmental assessment of the import of Russian Pu-238 shows that collision accidents on the open seas are more severe than those in inland waterways because of higher speeds, but less frequent because of lighter ship traffic (DOE 1993x:A-2). As a vessel nears port, it enters more congested waters and its speed decreases, but accident frequencies increase because of the increased ship traffic and relative proximity of one vessel to another. If PuO_2 were to be released in water in port areas or open seas, the study indicates that the oxide nature of the fuel results in a very low dissolution rate; and the aquatic chemistry of Pu is such that it preferentially binds with the sediment rather than remaining dissolved (DOE 1993x:A-3). The DOE study concluded that fire alone is not a credible means of causing a release, and any accident sequence that resulted in a release of contents must include exposure of the package containing the Pu to mechanical forces great enough to cause failure (that is, forces greater than required in Federal certification testing) (DOE 1993x:A-4). The probability of a severe ship collision, followed by a fire, is on the order of $1.0x10^{-8}$ per port call (DOE 1993x:A-3). Although the environmental assessment studies were performed specifically for the shipment of Pu-238, the results and conclusions are considered generally applicable to the shipment of Pu-239 and MOX fuel.

G.1.2.6 Security Considerations in the Global Commons, and at European MOX Facilities

The elements of security measures would be incorporated in the transportation plan DOE would complete for the shipment of PuO_2 to European MOX fuel fabrication sites, and for the return of fresh MOX fuel assemblies. The movement of these materials in the United States is addressed in Section 4.4.2.2 on the use of the SST transportation system. The safeguarding of the Pu to be shipped—from the time it leaves the SST in 6M-2R, Type B packaging in CRTs, through its loading into ISO containers, movement by port facility tractors, staging in the dock facilities, movement to its transport location on board, and unloading, staging, handling, and shipment to the MOX fuel fabrication facilities—would be addressed in the procedures specified in a transportation plan that DOE would prepare in accord with its guidance documents. This transportation plan would also address compliance with DOT, NRC, International Atomic Energy Agency (IAEA) regulations, safeguards and standards, and any additional measures deemed necessary to ensure that the transportation would be carried out in the most secure manner, considering the relative risks involved, and that recovery measures adequately mitigate the consequences in the event that security is breached. The DOT is the U.S. Competent Authority designated to carry out the provisions of the IAEA standards, and DOE would be responsible for the transportation plan to address the entire Pu transportation system for this campaign, from the point of origin in the United States to the delivery of the MOX fuel assemblies. In addition, the transportation plan would address Federal, State, and local regulations of the country where the MOX fuel fabrication facility is located.

Physical security of the Pu in transit would be provided in compliance with a security system referred to in the transportation plan. The DOT and NRC are responsible for the assessment of security measures for ship transport. The security system would include procedures for coping with circumstances that pose a threat to the Pu shipments and with other safeguards emergencies, and instructions for surveillance and escort requirements. These procedures would address the detection of abnormal presence of unauthorized persons, vehicles, or vessels in the vicinity of PuO_2 or MOX fuel shipments; the monitoring of the progress of the shipments; the notification of requirement for emergency actions; the maintenance of records required for verification that security has not been breached; and the documentation that proper procedures have been followed. Arrangements would be made with authorities at ports, and those along the routes to the MOX fuel fabrication facility responsible for responding to a security event or call for assistance. These arrangements would be approved in advance by the NRC, DOT, and State and local authorities. A shipment vessel in port would be protected by two armed escorts stationed on board or on the dock at a location permitting observation of the shipment. At sea, an authorized ship's officer would be responsible for providing the appropriate level of security and maintaining communication with the NRC.

The physical security threat to spent nuclear fuel in transport was recently evaluated by DOE in the *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Fuel* (DOE/EIS-0218, Volumes 1 and 2, Appendices D and H). The environmental impacts evaluated therein resulting from accidents and malicious attacks (explosion, breach of containment, fire) are relevant to the shipment of MOX fuel. Those analyses indicate that the consequences of the act to breach the packaging containment (explosions, penetration, fire) create a much higher injury and health risk than the release of the radioactive materials from the package. The packaging is designed so that the Pu is not present in sufficient quantities to create a nuclear criticality in the event of breach of the package containments. A nearby explosion unrelated to the Pu would not release Pu from the packages, and a penetration device (shaped charge, armor piercing projectiles) would most likely only rupture a single container, thus severely limiting the radioactive material hazard resulting from a malicious destructive act. The accident analyses described in this appendix address the risks associated with accidents resulting from a breach of security during transportation of PuO_2 and MOX (DOE 1996n:D-252–D-256; H-8–H-10).

Additional information on the shipment of Pu by sea can be found in *Safety of Shipments of Plutonium by Sea*, DOE/EM-0103, September 1993. This document was completed by DOE pursuant to Section 2904 of the *Energy Policy Act* of 1992, and addresses the shipment of Pu from one foreign port to another, and cites the conventions, treaties, and practices under which such shipments have been carried out and the codes and

standards used to ensure the safe and secure transport of Pu by sea. It notes that the shipment of Pu from France to Japan was done on a dedicated special purpose vessel that was accompanied by an armed escort ship capable of providing emergency support to the transport vessel.

For actions associated with this PEIS, transport of Pu by ship would be done by dedicated British Nuclear Fuel, Limited or COGEMA ships from military seaports in the United States to seaports in Great Britain or France. The transport would meet applicable IAEA requirements and the International Maritime Organization code. While in temporary storage at the seaports and during transport on the ship, appropriate escort security measures would be implemented.

G.2 HISTORICAL INTERSITE TRANSPORTATION SHIPMENT DATA

Table G.2–1 presents a 5-year (1990 through 1994) summary of the nonhazardous and hazardous cargo shipped by commercial carriers to and from each of the eight DOE sites included in this PEIS.

Table G.2–2 presents a summary, by chemical name, of all hazardous material shipped to and from Hanford Site, Idaho National Engineering Laboratory, Los Alamos National Laboratory, and Nevada Test Site for 1994. Table G.2–3 present a summary, by chemical name, of all hazardous material shipped to and from Oak Ridge Reservation, Pantex Plant, Rocky Flats Environmental Technology Site, and Savannah River Site for 1994.

G.3 HIGHWAY DISTANCE

Table G.3–1 shows the highway distance between the eight DOE sites being evaluated.

G.4 TRANSPORTATION EQUIPMENT

Packaging refers to a container and all accompanying components or materials necessary to perform its containment function. Packagings used by DOE for hazardous materials shipments are either certified to meet specific performance requirements or built to specifications described in DOT hazardous materials regulations (49 *Code of Federal Regulations* [CFR] Subchapter C). For relatively low-level radioactive materials, DOT Specification Type A packagings are used. These packagings are designed to retain their contents under normal transportation conditions. More sensitive radioactive materials shipments require use of highly sophisticated Type B packaging, designed and tested to prevent the release of contents under all credible transportation accident conditions.

Plutonium and HEU are DOE-unique hazardous materials that require special protection. In addition to meeting the stringent Type B containment and confinement requirements of the NRC's 10 CFR 71 and DOT's 49 CFR, packaging for nuclear weapons and components must be certified separately by DOE. DOE employs a closed, Government-owned and -operated Transportation Safeguards System for the intersite transport of nuclear weapons and components, including Pu and HEU. Specially designed SSTs are utilized to ensure high levels of safety and physical protection. Limited-life components are transported almost exclusively by DOE's contract air carrier.

As a representation of a typical Type B packaging used to transport weapons components, the testing sequence for the 6M, Type B packaging used for the shipment of HEU is described below. Pu packaging requires a similar, high level of protection. Most other radioactive and hazardous materials, such as LLW, would be transported by commercial truck. Figures G.4–1 through G.4–6 illustrate packaging types and a CRT used for the transport of materials.

Table G.2–1. Five-Year Summary of Cargo Shipments by Commercial Carrier To and From Department of Energy Sites

Site	1990 Shipments (number)	1990 Gross Weight (kg)	1991 Shipments (number)	1991 Gross Weight (kg)	1992 Shipments (number)	1992 Gross Weight (kg)	1993 Shipments (number)	1993 Gross Weight (kg)	1994 Shipments (number)	1994 Gross Weight (kg)
Hanford										
Hazardous	1,434	6,900,276	970	6,987,898	1,138	2,703,286	1,069	1,475,251	1,170	1,348,258
Nonhazardous	44,535	42,740,651	48,881	42,828,946	60,301	32,069,447	71,303	38,498,165	74,448	15,414,828
All cargo	45,969	49,640,927	49,851	49,816,844	61,439	34,772,733	72,372	39,973,416	75,618	16,763,086
INEL										
Hazardous	1,598	19,601,146	1,672	23,719,753	1,641	18,553,980	1,864	22,006,964	1,852	16,108,334
Nonhazardous	31,150	19,774,939	34,586	10,824,950	37,379	12,590,160	40,122	19,569,410	41,419	11,825,648
All cargo	32,748	39,376,085	36,258	34,544,703	39,020	31,144,140	41,986	41,576,374	43,271	27,933,982
LANL										
Hazardous	851	544,668	680	316,974	1,089	363,818	1,133	345,403	692	214,510
Nonhazardous	28,266	4,129,802	28,757	3,943,075	36,805	1,855,129	46,663	2,617,906	49,453	3,327,743
All cargo	29,117	4,674,470	29,437	4,260,049	37,894	2,218,947	47,796	2,963,309	50,145	3,542,253
[Text deleted.]										
NTS										
Hazardous	1,742	20,627,008	1,325	15,777,433	1,432	17,834,469	1,143	15,845,750	1,324	22,384,272
Nonhazardous	23,107	38,455,253	21,898	36,197,342	19,938	31,944,034	16,568	10,622,714	14,839	21,567,339
All cargo	24,849	59,082,261	23,223	51,974,775	21,370	49,778,503	17,711	26,468,464	16,163	43,951,611
ORR										
Hazardous	2,141	3,592,513	1,433	2,254,290	3,896	8,546,187	3,130	11,765,312	3,169	6,438,748
Nonhazardous	55,921	8,176,837	57,217	6,905,370	69,771	7,448,941	74,479	5,409,370	75,684	7,409,628
All cargo	58,062	11,769,350	58,650	9,159,660	73,667	15,995,128	77,609	17,174,682	78,853	13,848,376
Pantex										
Hazardous	1,869	407,622	1,339	462,842	1,124	601,087	1,080	597,720	612	328,329
Nonhazardous	8,494	1,262,617	10,085	1,314,989	10,191	1,317,023	11,135	1,733,062	11,760	1,732,379
All cargo	10,363	1,670,239	11,424	1,777,831	11,315	1,918,110	12,215	2,330,782	12,372	2,060,708
RFETS										
Hazardous	1,031	9,063,839	620	3,072,285	553	3,394,375	640	3,409,414	671	3,389,440
Nonhazardous	14,841	5,749,752	15,409	4,284,776	14,427	4,002,657	13,555	4,573,259	13,612	4,204,062
All cargo	15,872	14,813,591	16,029	7,357,061	14,980	7,397,032	14,195	7,982,673	14,283	7,593,502

Table G.2–1. Five-Year Summary of Cargo Shipments by Commercial Carrier To and From Department of Energy Sites—Continued

Site	1990 Shipments (number)	1990 Gross Weight (kg)	1991 Shipments (number)	1991 Gross Weight (kg)	1992 Shipments (number)	1992 Gross Weight (kg)	1993 Shipments (number)	1993 Gross Weight (kg)	1994 Shipments (number)	1994 Gross Weight (kg)
SRS										
Hazardous	1,151	4,049,534	643	3,192,682	1,462	2,625,821	1,386	2,508,277	1,147	2,754,435
Nonhazardous	36,012	227,513,797	33,870	151,211,460	34,348	136,905,940	34,816	224,005,944	25,915	241,279,894
All cargo	37,163	231,563,331	34,513	154,404,142	35,810	139,531,761	36,202	226,514,221	27,062	244,034,329

Note: Gross weight includes the weight of the package.

Source: SAIC 1995a:1.

Table G.2–2. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994

Commodity	Hanford Shipments (number)	Hanford Gross Weight (kg)	INEL Shipments (number)	INEL Gross Weight (kg)	LANL Shipments (number)	LANL Gross Weight (kg)	NTS Shipments (number)	NTS Gross Weight (kg)
Acetylene gas	1	22			1	95		
Aluminum nitrate	2	1,087	9	152,335			2	144
Aluminum sulfate, solid	1	4,798	1	3	1	142		
Ammonia, anhydrous	6	242	4	383	1	41	1	1,487
Ammonium fluoride								
Ammonium hydroxide			3	44				
Ammonium sulfate			1	3			1	13
Argon	11	1,313	2	284	3	354	20	5,975
Asbestos articles	2	5,516	2	1	1	1		
Asphalt			1	513			6	3,288,218
Beryllium metal					1	3		
Beryllium metal or powder								
Cadmium nitrate			3	23				
Cadmium sulfate			1	3				
Calcium nitrate			1	142				
Chlorine	11	17,824	5	429	1	3	1	5,670
Class A poison	13	590	4	190	3	18	2	296
Class B poison	5	2,900	1	107				

Table G.2–2. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	Hanford		INEL		LANL		NTS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Combustible liquid, n.o.s.	9	3,592	9	346	6	1,529	10	55,477
Corrosive material, n.o.s.	116	106,517	222	157,841	28	2,458	29	6,205
Dry ice	4	19			49	427		
Empty haz. cntrs. (Non-ram)	10	2,463	2	6,078			76	292,447
Enriched boric acid			2	817				
Env haz. subst. (Marine pollutant)							1	5,443
Env. hazardous substance	4	162	3	59				
Etiologic agent, n.o.s.					1	4		
Explosives, n.o.s. (Class 1.1)			2	349	8	426	3	4,891
Explosives, n.o.s. (Class 1.2)								
Explosives, n.o.s. (Class 1.3)								
Explosives, n.o.s. (Class 1.4)	2	148	3	1,195	7	376		
Ferrous sulfamate							1	5
Ferrous sulfate			1	2				
Flammable gas, n.o.s.	24	2,664	21	7,298	43	35,757	3	178
Flammable liquid, n.o.s.	97	28,101	102	31,629	23	4,162	21	2,169
Flammable solid, n.o.s.	1	51	12	18,586	14	285	2	214
Fluoboric acid								
Fuel oil (Diesel, 1-6, etc.)			336	9,681,302	5	7,146	122	4,093,274
Gasoline			60	1,592,185	1	2	94	2,741,403
Hazardous waste (Non-ram)	1	7,258			1	66	2	12
Helium	20	7,145	13	2,326	27	18,439	5	1,278
Hydrocarbon gas, compressed or liquefied								

Table G.2–2. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	Hanford		INEL		LANL		NTS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Hydrochloric acid	14	910	10	35	2	2,169	5	724
Hydrofluoric acid			1	5			3	633
Hydrofluoric acid solution, spent	3	256	1	481	1	1	3	74
Hydrogen gas	2	181			1	33		
Hydrogen peroxide	6	8,216	1	32			2	343
Irritant, n.o.s.					2	2		
Isobutane, compressed or liquefied					2	1,134	1	3
Lithium metal	6	224	1	1	3	5		
Lubricating oil			39	2,826	2	182	33	31,307
Magnesium, powder, metal strip					2	11		
Mercuric nitrate					1	15	1	1
Methanol, liquid							1	40
Methyl isobutyl ketone			3	4,193			7	150,547
Misc. hazardous material			3	1,341				
N-dodecane								
Natural gas, compressed or liquefied							1	1,270
Nitric acid (incl. fuming)	25	3,167	9	614	1	1	5	1,098
Nitric acid (over 40%)	1	40	2	43,500			1	334
Nitric acid, fuming	3	291						
Nitrogen	4	3,606	110	1,623,986	8	277	20	14,370
Non-flammable gas, n.o.s.	145	62,388	122	13,025	91	28,603	25	16,682
Organic peroxide, n.o.s.	1	1	1	1	1	1,194		
Orm A, n.o.s.								
Orm B, n.o.s.								
Orm D, consumer commodity			2	554				

Table G.2–2. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	Hanford		INEL		LANL		NTS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Orm E, n.o.s.			1	7,521				
Other regulated material, liquid			4	269				
Other regulated material, solid			9	660			3	3,612
Oxidizer, n.o.s.	91	11,693	18	1,363	4	3,023	5	271
Oxygen	9	1,273	19	289,616	3	166	4	704
Poison, liquid, n.o.s.	7	400	29	1,375	9	1,026		
Poison, solid, n.o.s.	14	235	15	587	7	98	1	19
Propane, compressed or liquefied			1	21	1	272	2	158
RAM, empty pkgs	30	156,726	41	224,474	49	35,462	1	1,016
RAM, fissile, <20% U-235								
RAM, fissile, >20% U-235								
RAM, fissile, HRCQ	3	65,317						
RAM, fissile, HRCQ, IR PINS			1	100				
RAM, fissile, HRCQ, UNIR PINS	1	21,772						
RAM, fissile, n.o.s.	1	73	5	17,327	10	669		
RAM, fissile, UNIR PINS			9	63,539				
RAM, fissile, waste								
RAM, HRCQ, special	7	107,002						
RAM, instr. & articles	25	688	2	41	1	154		
RAM, LSA, n.o.s.	6	14,590	101	866,798	5	4,651		
RAM, LSA, UF_6					1	277		
RAM, LSA, waste	34	443,212					688	11,291,791
RAM, ltd. quant, n.o.s.	161	5,429	234	785,852	124	3,257	3	3,570
RAM, medical isotopes					6	31		
RAM, n.o.s.	131	28,340	80	225,191	75	21,660	25	2,169
RAM, n.o.s., HRCQ			2	13,395	1	16,329		

Table G.2–2. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	Hanford		INEL		LANL		NTS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
RAM, n.o.s., special	27	2,338	91	38,863	5	3,889	8	5,708
RAM, n.o.s., waste	12	161,664						
RAM, U-metal, pyrop					1	1		
RAM, UO_x, n.o.s.			1	1				
Small arms ammunition			1	36			1	387
Sodium hydroxide (caustic soda)	13	28,331	13	77,621	7	8,218	7	8,389
Sodium metal, (non-RAM)	3	315	5	44				
Sodium nitrate	10	1,667			1	5	1	3
Spontaneously combustible material	3	4	3	30	3	47		
Sulfuric acid	9	23,408	13	141,353	2	403	1	1
Toxic gas, inhalation hazard	13	284	7	655	26	7,500		
Trichloroethane 1,1,1			2	220				
Wet cell batteries	10	1,804	14	6,322	9	2,013	64	344,251
Total	1,170	1,348,257	1,852	16,108,341	692	214,512	1,324	22,384,272

Note: Gross weight (kg) includes the weight of the package; n.o.s.=not otherwise specified.

Source: SAIC 1995a:2.

Table G.2–3. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994

Commodity	ORR		Pantex		RFETS		SRS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Acetylene gas	13	8,101			5	1,714	17	3,372
Aluminum nitrate	1	5			1	2	2	53
Aluminum sulfate, solid	1	378			1	962	2	6,277
Ammonia, anhydrous	3	686			2	252	4	587
Ammonium fluoride	1	1						
Ammonium hydroxide			1	34	4	397		
Ammonium sulfate								
Argon	199	430,223	8	1,250	48	797,649	33	82,713
Asbestos articles	33	37,544						
Asphalt			1	540	1	16		
Beryllium metal								
Beryllium metal or powder	1	6,638						
Cadmium nitrate	1	489			2	7		
Cadmium sulfate								
Calcium nitrate	1	1	1	2	3	16		
Chlorine	35	63,200	4	1,780	3	895		
Class A poison	2	10						
Class B poison	2	3,680	2	1,343				
Combustible liquid, n.o.s.	28	2,237	7	1,142	11	186	3	119
Corrosive material, n.o.s.	183	213,634	60	15,996	32	5,654	120	290,507
Dry ice	153	45,406			33	496		
Empty haz. cntrs. (non-RAM)	210	576,434						
Enriched boric acid								
Env haz. subst. (marine pollutant)	3	80					1	20
Env. haz. subst.	10	4,934			2	302		
Etiologic agent, n.o.s.	1	144						
Explosives, n.o.s. (Class 1.1)			27	25,058				

Table G.2–3. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	ORR		Pantex		RFETS		SRS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Explosives, n.o.s. (Class 1.2)			1	40			5	29,821
Explosives, n.o.s. (Class 1.3)			2	2,650				
Explosives, n.o.s. (Class 1.4)	7	3,870	93	14,008	6	6,588	8	4,859
Ferrous sulfamate	1	2,749	1	21				
Ferrous sulfate	2	2,041						
Flammable gas, n.o.s.	42	24,301	13	1,734	4	4,621	25	57,028
Flammable liquid, n.o.s.	140	54,056	54	6,947	20	1,278	33	28,406
Flammable solid, n.o.s.	35	360	58	6,068	1	11	1	7
Fluoboric acid	1	1						
Fuel oil (diesel, 1-6, etc.)	109	366,209			37	434,956	3	2,188
Gasoline	166	624,837			37	763,986	10	4,790
Hazardous waste (non-RAM)	3	12	1	19	2	8,865	8	1,438
Helium	33	42,913	11	640	9	104,851	21	27,444
Hydrocarbon gas, compressed or liquefied								
Hydrochloric acid	16	95	6	20	19	1,735	25	43,606
Hydrofluoric acid	2	59			3	284	7	6,885
Hydrofluoric acid solution, spent	1	4			2	495	1	27
Hydrogen gas	11	39,032	3	217	2	1,062	13	2,620
Hydrogen peroxide	8	1,911	1	2	2	54	9	3,870
Irritant, n.o.s.								
Isobutane, compressed or liquefied	2	1						
Lithium metal	24	3,290	9	845				
Lubricating oil	13	1,589	14	3,766	1	260	22	8,391
Magnesium, powder, metal strip	10	6					1	39

Table G.2–3. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	ORR		Pantex		RFETS		SRS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
Mercuric nitrate								
Methanol, liquid	1	1			3	26	1	123
Methyl isobutyl ketone								
Misc. hazardous material	19	653	1	13	1	8	1	75
N-dodecane								
Natural gas, compressed or liquefied							1	373
Nitric acid (incl. fuming)	14	20,827	3	59	32	4,021	22	6270
Nitric acid (over 40%)	1	18					4	306
Nitric acid, fuming	1	2					3	1,143
Nitrogen	58	269,550	2	384	115	877,031	32	69,318
Non-flammable gas, n.o.s.	141	103,053	29	6,310	37	15,839	205	1,477,767
Organic peroxide, n.o.s.	2	2					2	11
Orm A, n.o.s.	2	7,874						
Orm B, n.o.s.					1	12,791		
Orm D, consumer commodity					1	54	10	4,619
Orm E, n.o.s.	5	11,544						
Other regulated material, liquid	3	79			4	6,373	1	626
Other regulated material, solid	1	159						
Oxidizer, n.o.s.	47	1,486	2	35	17	851	4	15,321
Oxygen	24	4,811	2	258	9	6,173	20	26,036
Poison, liquid, n.o.s.	47	5,880	4	124	11	756	1	1
Poison, solid, n.o.s.	50	258			5	393	1	1
Propane, compressed or liquefied	5	227			2	301	1	68
RAM, empty pkgs	68	313,080	88	159,735	12	4,474	17	24,540
RAM, fissile, <20% U-235	3	6,275						

Table G.2–3. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	ORR		Pantex		RFETS		SRS	
	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)	Shipments (number)	Gross Weight (kg)
RAM, fissile, >20% U-235	15	2,318						
RAM, fissile, HRCQ								
RAM, fissile, HRCQ, IR PINS							17	212,305
RAM, fissile, HRCQ, UNIR PINS								
RAM, fissile, n.o.s.	10	36,770	1	1,659			2	220
RAM, fissile, UNIR PINS								
RAM, fissile, waste			1	7,254	1	7,971		
RAM, HRCQ, special	2	4,364						
RAM, instr. & articles	9	5,875	5	91				
RAM, LSA, n.o.s.	454	1,120,758	9	466	37	138,597		
RAM, LSA, UF_6	66	1,270,833						
RAM, LSA, waste	6	111,223			9	151,142		
RAM, ltd. quant., n.o.s.	209	197,911	48	57,469	18	4,201	239	64,891
RAM, medical isotopes	107	390						
RAM, n.o.s.	135	124,546	23	3,903	8	1,269	32	69,099
RAM, n.o.s., HRCQ	1	13,744						
RAM, n.o.s., special	58	38,376	6	89	1	4	6	216
RAM, n.o.s., waste	1	109						
RAM, U-metal, pyrop	3	529						
RAM, UO_x, n.o.s.	1	2						
Small arms ammunition	1	1,013	4	4,913	5	431		
Sodium hydroxide (caustic soda)	27	70,840			6	812	52	39,585
Sodium metal, (non-RAM)	3	65						
Sodium nitrate	3	233	1	2	3	331	3	169
Spontaneously combustible material	1	3			1	11		
Sulfuric acid	13	103,875			6	918	13	81,353

Table G.2–3. Summary of Hazardous Materials Shipped To and From Department of Energy Sites–1994—Continued

Commodity	ORR Shipments (number)	ORR Gross Weight (kg)	Pantex Shipments (number)	Pantex Gross Weight (kg)	RFETS Shipments (number)	RFETS Gross Weight (kg)	SRS Shipments (number)	SRS Gross Weight (kg)
Toxic gas, inhalation hazard	16	340	1	653	3	418	7	1,675
Trichloroethane 1,1,1	8	247	2	108				
Wet cell batteries	21	27,448	2	684	30	16,652	81	84,262
Total	3,169	6,438,750	612	328,331	671	3,389,442	1,152	2,754,435

Note: Gross weight (kg) includes the weight of the package; n.o.s.=not otherwise specified.
Source: SAIC 1995a:2.

Table G.3–1. Highway Distance Between Department of Energy Sites (kilometers)

Site	Hanford	NTS	INEL	Pantex	ORR	SRS	RFETS	LANL
Hanford	0	1,491	850	2,497	3,867	4,299	1,813	1,998
NTS	1,491	0	1,138	1,539	3,272	3,610	1,359	1,220
INEL	850	1,138	0	1,721	3,077	3,523	1,037	1,311
Pantex	2,497	1,539	1,721	0	1,732	2,070	726	535
ORR	3,867	3,272	3,077	1,732	0	531	2,145	2,267
SRS	4,299	3,610	3,523	2,070	531	0	2,590	2,605
RFETS	1,813	1,359	1,037	726	2,145	2,590	0	630
LANL	1,998	1,220	1,311	535	2,267	2,605	630	0

Source: DOE 1991j; DOE 1992o:3; McNally 1990a.

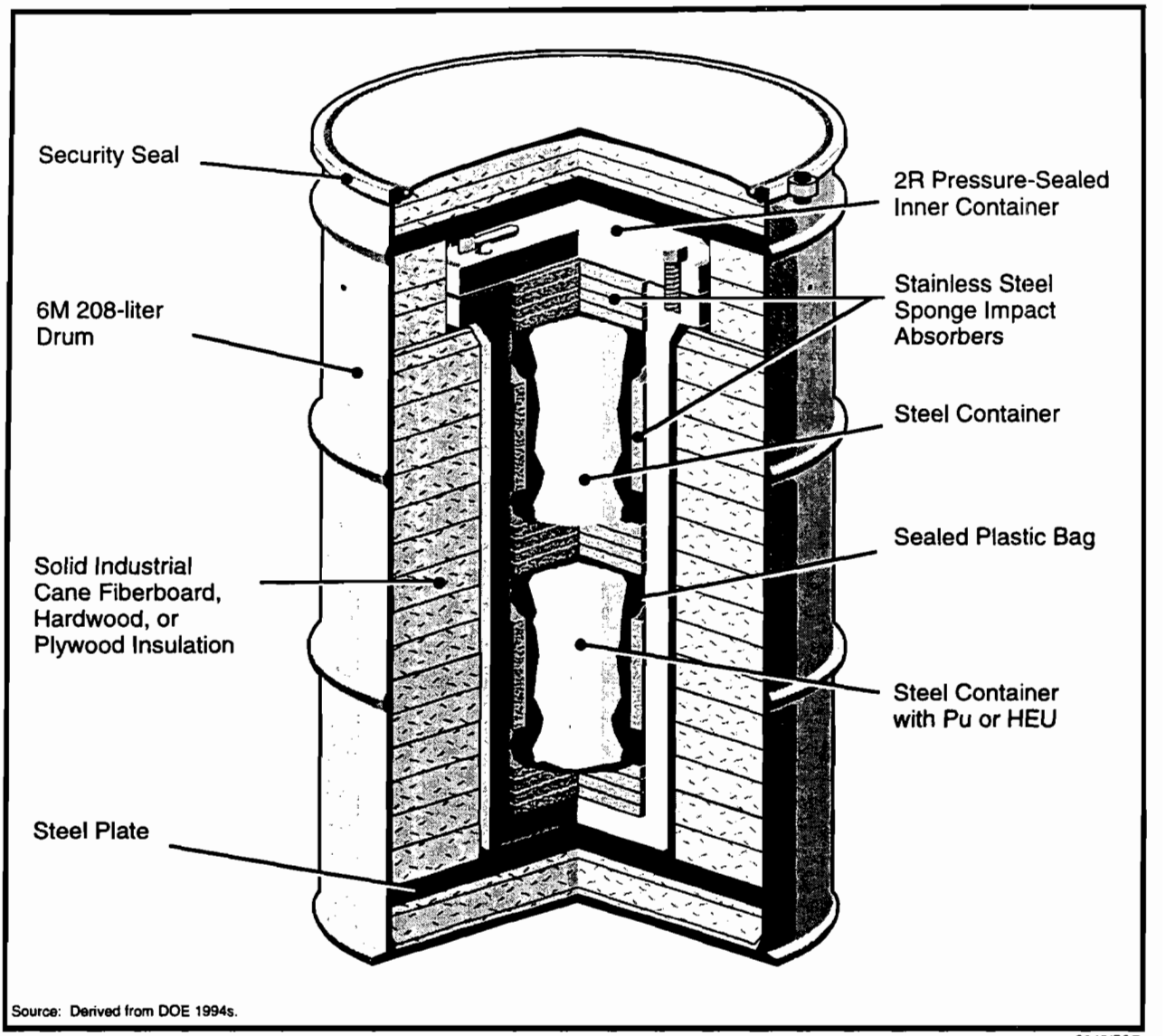
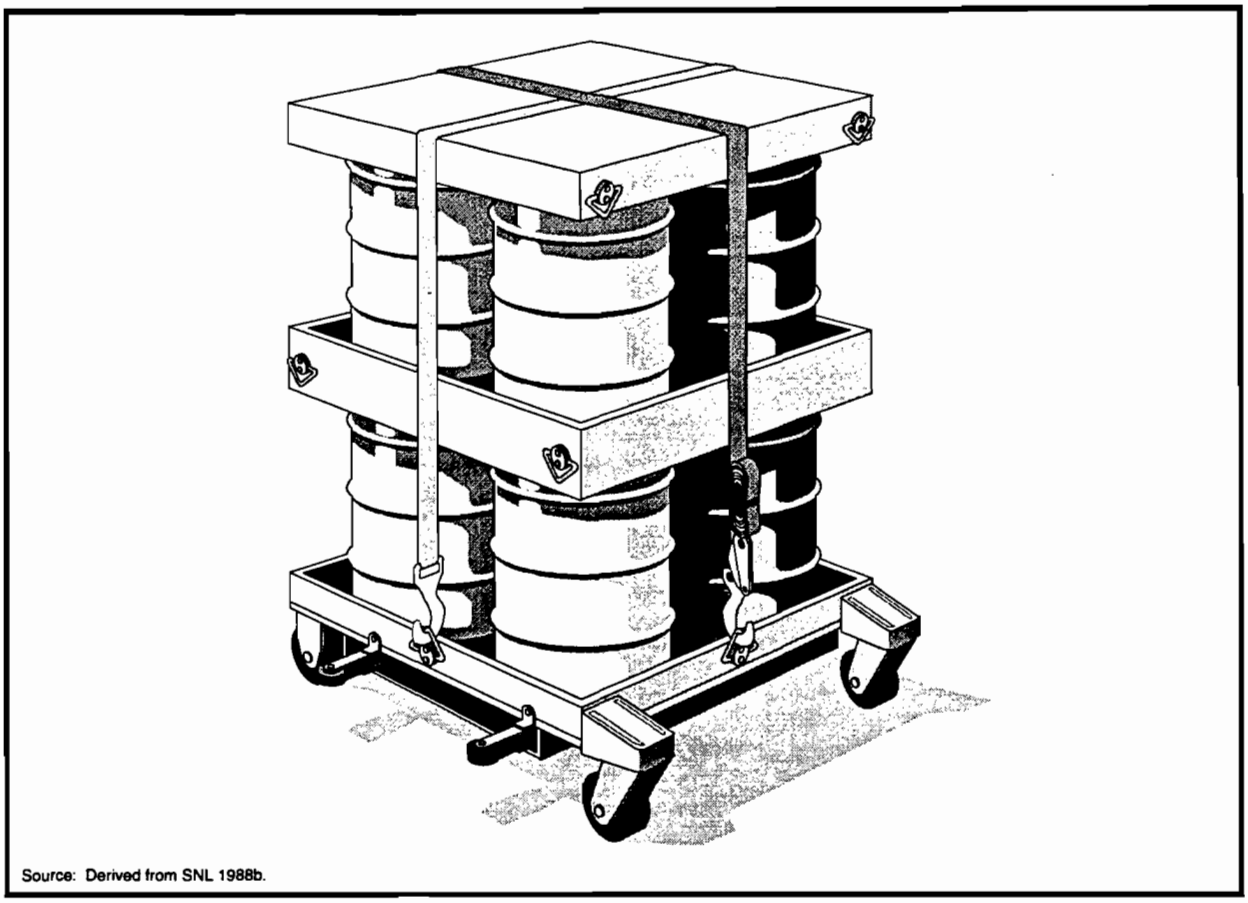


Figure G.4–1. Typical Assembly of 6M, Type B Packaging for Plutonium (Other Than Pits) or Highly Enriched Uranium



Source: Derived from SNL 1988b.

2949/S&D

Figure G.4–2. Cargo Restraint Transporter Loaded With Drums.

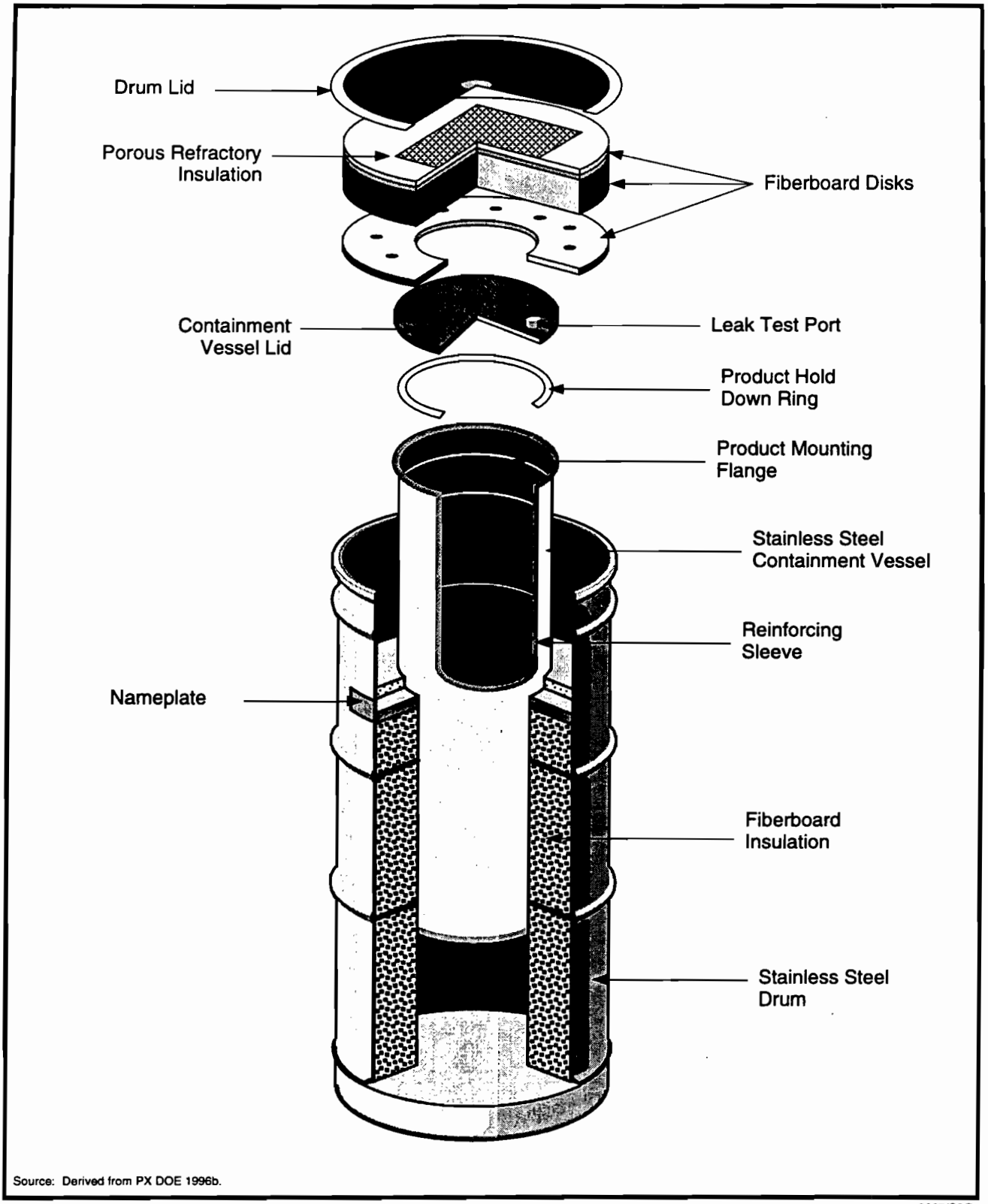
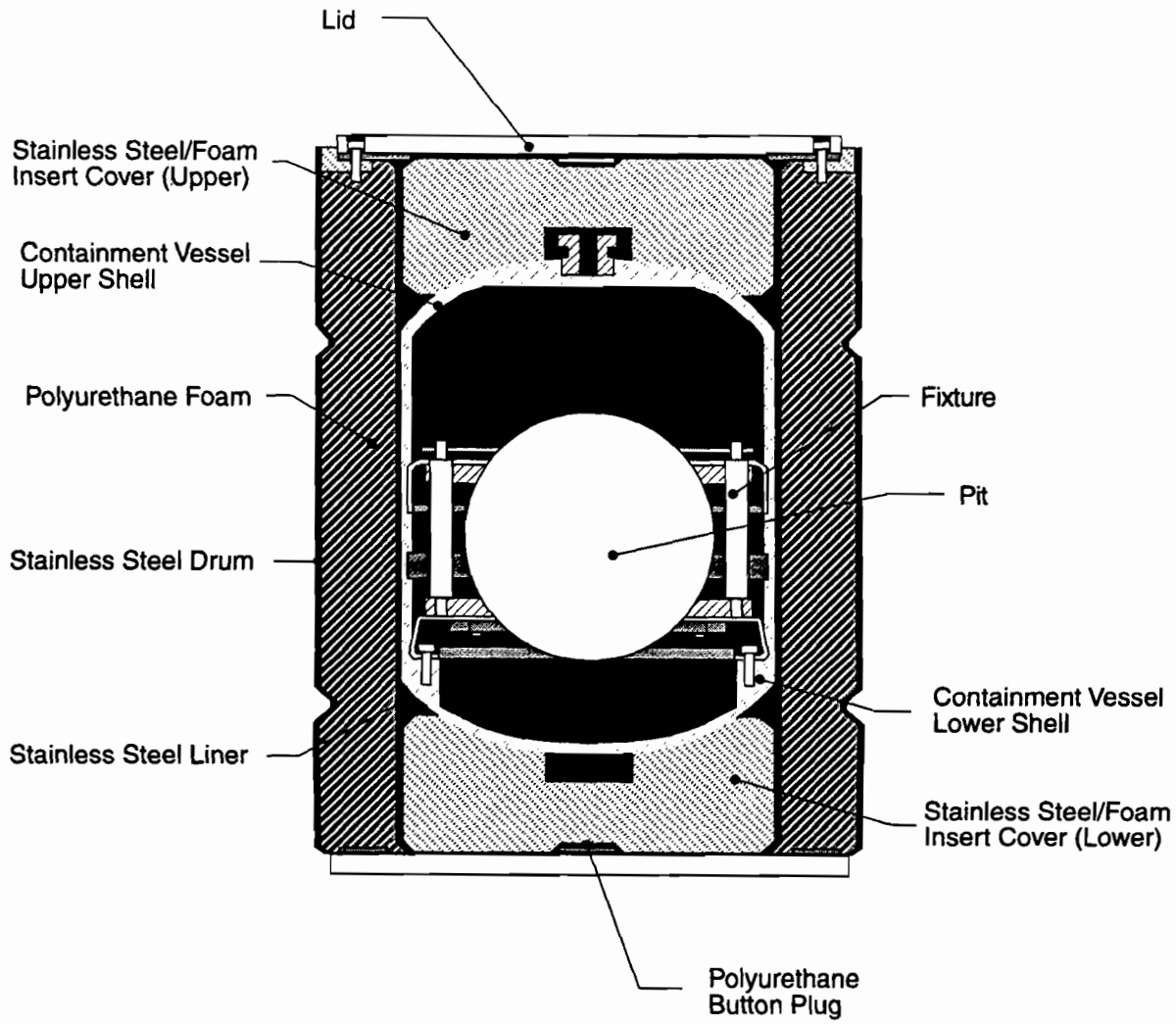


Figure G.4–3. Assembly of FL, Type B Packaging for the Transport of Plutonium Pits.



Note: Drawing not to scale.

Source: Derived from PX DOE 1996b.

3174/S&D

Figure G.4–4. AT-400A Packaging for the Transport of Plutonium Pits.

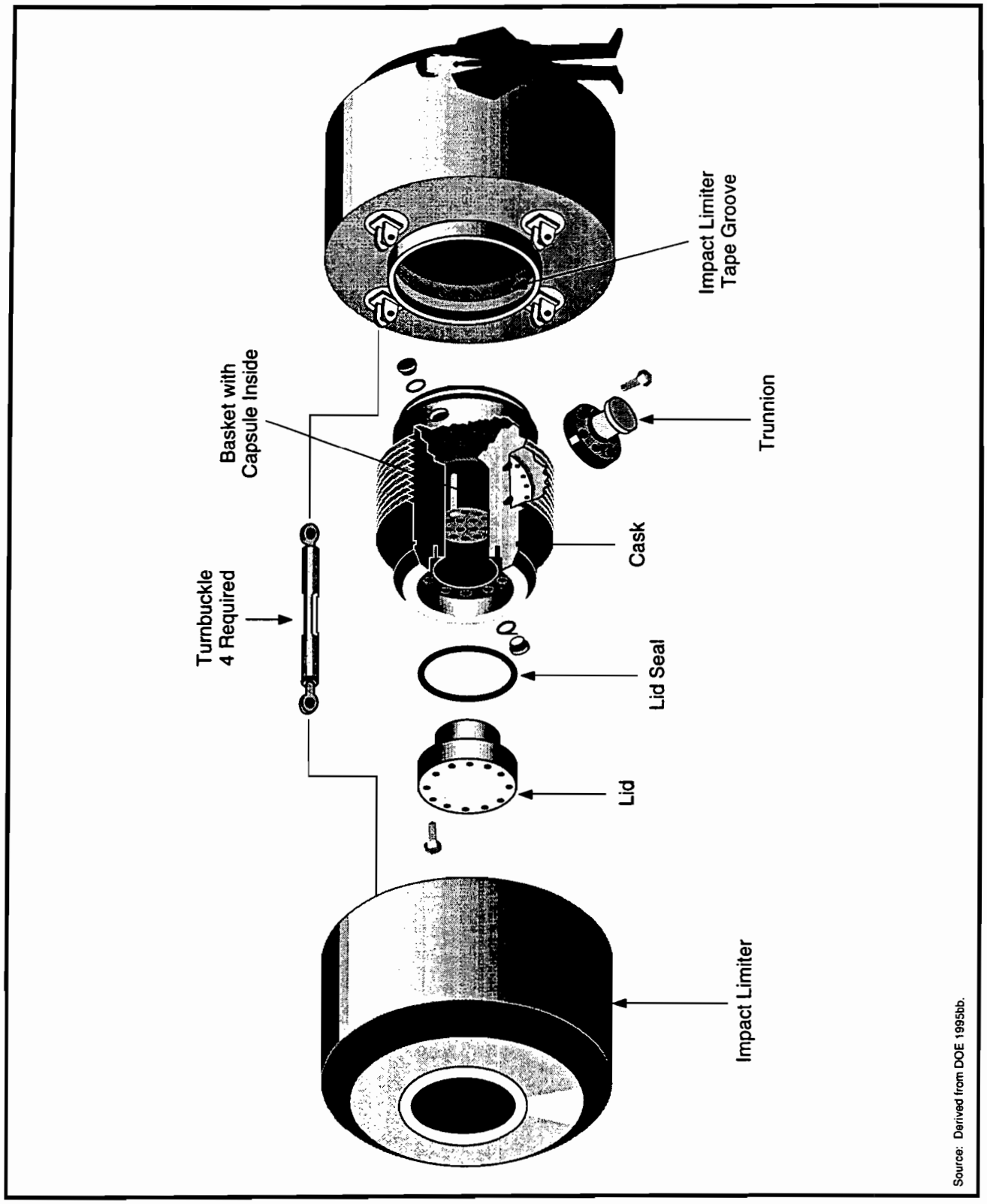


Figure G.4–5. Representation of the BUSS Cask for the Transport of Cesium Material.

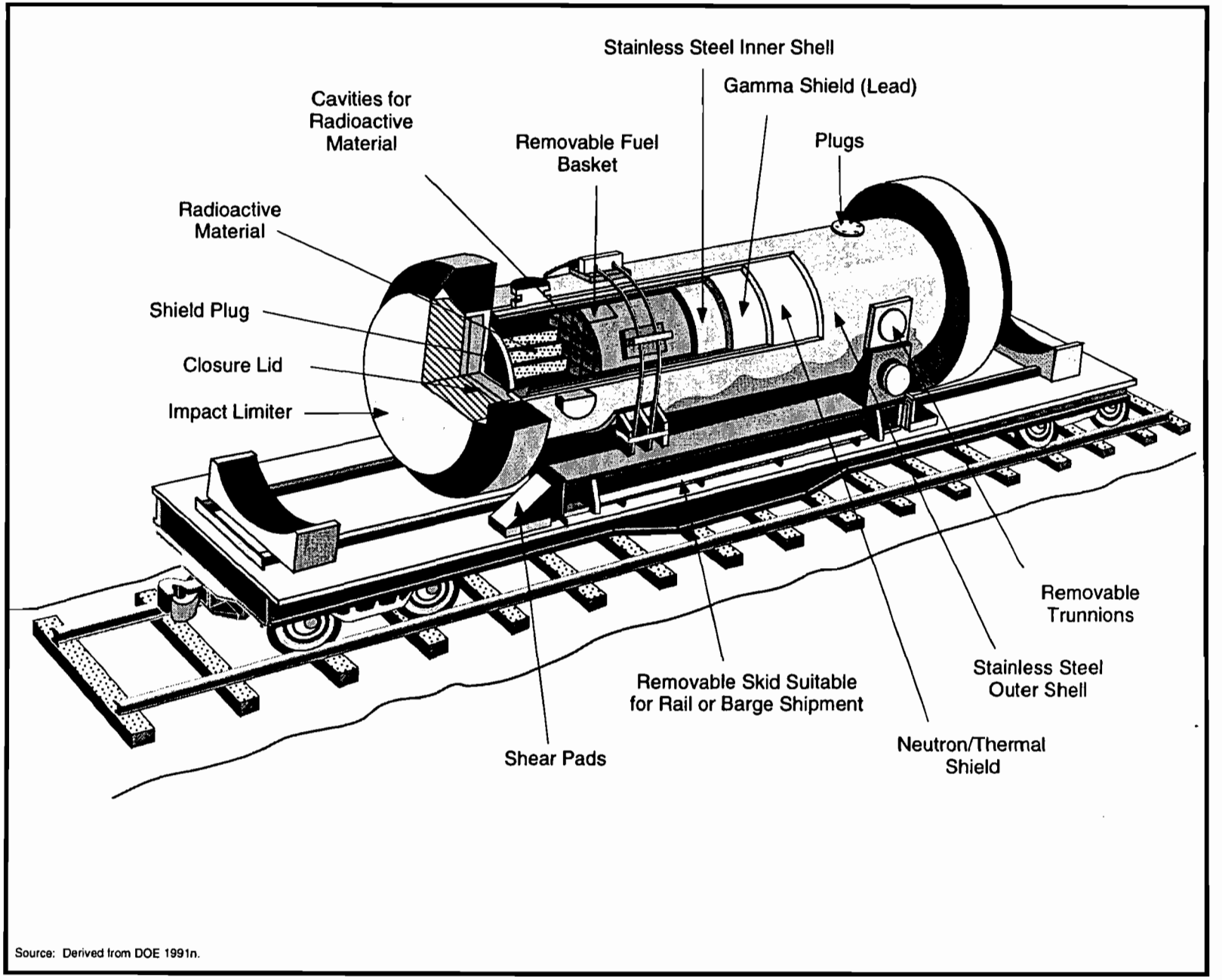


Figure G.4–6. Diagram of a Representative Spent Fuel Cask With Similar Characteristics to Be Employed for the Transport of Immobilized Plutonium.

G.5 6M, TYPE B RADIOACTIVE MATERIAL SHIPMENT PACKAGING TEST SEQUENCE

In addition to meeting DOT standards demonstrating it can withstand normal conditions of transport without loss or dispersal of its radioactive contents, the model 6M, Type B packaging used for DOE shipments must survive certain severe hypothetical accident conditions that demonstrate resistance to impact, puncture, fire, and water submersion. Test conditions do not duplicate accident environments, but rather, produce damage equivalent to extreme and unlikely accidents. The 6M, Type B packaging is judged as surviving extreme sequential testing if it retains all its contents except for minuscule allowable releases, and the dose rate outside the packaging does not exceed 1 rem/hr at a distance of 1 m (3.3 ft) from the package surface. Drum sizes (outer package) can vary from 38 to 416 liters (10 to 110 gallons).

The complete sequence of tests is listed below.

- **Drop Test.** A 9-m (30-ft) drop onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.
- **Puncture Test.** A 1-m (3.3-ft) drop onto the upper end of a 15-centimeter (6-inch) diameter solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface.
- **Thermal Test.** An exposure for no less than 30 minutes to a heat flux no less than that of a radiation environment of 800 °C (1,475 °F) with an emissivity coefficient of at least 0.9.
- **Water-Immersion Test.** A subjection to water pressure equivalent to immersion under a head of water of at least 15 m (50 ft) for no less than 8 hours.

The regulatory test conditions for the 6M, Type B packaging and other similar packaging are much more demanding than they might appear. For example, an impact on a very hard surface (desert caliche) at more than 322 km (200 mi) per hour is not as likely to deform the packaging as would a drop of 9 m (30 ft) onto an unyielding target.

A typical 6M, Type B packaging approved for use by DOE is covered by Certificate of Compliance Number 9859, dated January 5, 1994. The 6M, Type B packaging is made up of several components each with an integral engineered role in containment and confinement of the radioactive material being shipped. Although 6M, Type B packaging has been involved in severe accidents, the integrity of the packaging has never been compromised.

It is noted that there is some controversy concerning the adequacy of the Type B packaging. However, these packages are currently certified as safe for transporting radioactive materials. If the safety certification for the packaging is withdrawn, new analysis will be required.

G.6 SAFE SECURE TRANSPORT

Since 1947, DOE and its predecessor agencies have moved nuclear weapons, nuclear weapons components, and special nuclear materials by a variety of commercial and Government transportation modes. In the late 60s, worldwide terrorism and acts of violence prompted a review of procedures for safeguarding these materials. As a result, a comprehensive new series of regulations and equipment was developed to enhance the safety and security of these materials in transit. Subsequently, the Transportation Safeguards Division (TSD) was established in 1975 at the DOE Albuquerque Operations Office. TSD modified and redesigned transport equipment to incorporate features that more effectively enhance self protection and deny unauthorized access to the materials. During that time, TSD curtailed the use of commercial transportation systems and moved to a total Federal operation.

Management, control, and direction of TSD is centralized at Albuquerque Operation Office. Both the Federal officers who drive the transportation vehicles and the escorts are Nuclear Materials Couriers. There are three courier operations centers, located at Amarillo, Texas, Oak Ridge, Tennessee, and Albuquerque, New Mexico. Approximately 100 shippers and receivers of special nuclear material and other sensitive materials are served at locations throughout the continental United States.

Since its establishment in 1975, TSD has accumulated over 110 million km (70 million mi) of over-the-road experience transporting DOE-owned cargo with no accidents causing a fatality or release of radioactive material. This is due largely to the TSD philosophy that safety and security are of equal and paramount importance in the accomplishment of DOE's transportation safeguards mission.

The SST is a specially designed part of an 18-wheel rig that incorporates various deterrents to prevent unauthorized removal of cargo. The trailer has been designed to afford the cargo protection against damage in the event of an accident. This is accomplished through superior structural characteristics and a highly reliable cargo tiedown system similar to that used aboard aircraft. The thermal characteristics of the SST would allow the trailer to be totally engulfed in a fire without incurring damage to the cargo. The tractors are standard production units that have been modified to provide the couriers protection against attack. Other vehicles that make up the convoy may include Ford vans and Chevrolet Suburbans. These tractors and escort vehicles are equipped with communications, electronic, radiological monitoring, and other equipment that further enhance en route safety and security. The vehicles utilized by TSD must meet maintenance standards significantly more stringent than those for similar commercial transport equipment. All vehicles undergo an extensive maintenance check before every trip, as well as periodic preventative maintenance inspections. In addition, these vehicles are replaced more frequently than commercial shippers. As a result, TSD experiences few en route breakdowns and has had no accidents due to equipment malfunction.

The TSD makes every effort to ensure its convoys do not travel during periods of inclement weather. Should the convoys encounter adverse weather, provisions exist for the convoys to seek secure shelter at previously identified facilities. Although TSD provides sleeper berths in all vehicles, couriers accompanying TSD shipments do not exceed 32 hours of continuous travel without being afforded the opportunity for 8 hours of uninterrupted, stationary bed rest. TSD has also imposed a maximum 88-km/hr (55-mph) speed limit on its convoys, even if the posted limit is greater.

Security Communications is a nationwide communications system operated by TSD and located in Albuquerque. This system provides a capability to monitor the status and location of every convoy and maintain real-time communications 24 hours a day, 365 days a year with every convoy. The control center maintains an emergency contact directory of Federal, State, and local response organizations located throughout the contiguous United States. This capability is available to TSD 24 hours a day, 365 days a year.

Armed Nuclear Materials Couriers accompany each shipment containing special nuclear material. They also drive the highway tractors and escort vehicles while operating the communications and other convoy equipment. Couriers are non-uniformed Federal officers and are authorized by the *Atomic Energy Act* to make arrests and carry firearms in the performance of their duties. They carry both a photo identification card and shield which certify their Federal status. Couriers are required to obey all traffic laws and will cooperate fully with law enforcement officers. After careful screening and selection, courier trainees undergo a 12-week basic training course, during which they receive instruction in tractor-trailer driving, electronic and communications systems operation, and firearms. Tests in operating procedures, physical fitness, driving, firearms, and other job related subjects must be passed in order for a courier to be certified. Following basic training, the courier spends the balance of the first year in on-the-job training. The first year of employment is probationary, and the courier must successfully complete it to be retained. Couriers are given in-service training throughout their careers. These classes are designed to refresh and update the training taught during basic training, in addition to preparing couriers for demonstrations or armed attacks. Subjects such as team tactics, terrorist tactics, and new adversary

technology are taught. In addition, physical and firearm proficiency is tested. Couriers must continue to meet periodic qualification requirements relative to firearms, physical fitness, and driving proficiency. They must also undergo and pass an annual medical examination for continued certification under the DOE Personnel Assurance Program. In addition, couriers are subject to DOE's randomized drug and alcohol testing program. If a courier fails to meet any of the minimum requirements necessary for courier certification, the individual is temporarily removed from active status and provided additional training until demonstrated performance reaches an acceptable level.

The TSD has a liaison program through which it communicates with law enforcement and public safety agencies throughout the country, making them aware of these shipments. TSD has established procedures should an SST be stopped by an officer. The liaison program provides law enforcement officers information to assist them in recognizing one of these vehicles should it be involved in an accident, and what actions to take in conjunction with the actions of the couriers in the rig and the escort vehicles. Through the liaison program, TSD offers in-depth briefings at the State level (DOE 1993ff:1-4).

Appendix H
High-Level Waste Forms Comparative Analysis

H.1 METHODOLOGY

This appendix evaluates various plutonium (Pu) forms for potential disposal in a geologic repository. Although a repository site has not yet been recommended for development by the President and approved by Congress, this programmatic environmental impact statement (PEIS) assumes (for analysis purposes only) the existence of a hypothetical repository, managed by the Department of Energy (DOE) Office of Civilian Radioactive Waste Management, at the Yucca Mountain Site in southern Nevada. In accordance with the *Nuclear Waste Policy Act* (NWPA) of 1982, as amended by the NWPA Amendments of 1987 (42 USC 10101), DOE is evaluating the suitability of the Yucca Mountain Site as a potential geologic repository for the disposal of spent nuclear fuel and high-level waste (HLW). Such a repository, if approved under the provisions of the NWPA, would serve primarily as the disposal site for commercial and DOE-owned spent nuclear fuel and HLW. Certain highly radioactive material, which the Nuclear Regulatory Commission (NRC) determines by rule requires permanent isolation, may also be disposed of as HLW in a geologic repository. Such a NRC determination or legislative clarification may be required to dispose of the immobilized forms that would result from the Immobilization Alternatives. Since no waste forms are currently licensed for disposal in an HLW repository, data for forms under consideration in this PEIS for ultimate disposal in a repository are compared to data for those forms currently being evaluated for disposal in an NWPA-licensed repository (that is, commercial and DOE-owned spent nuclear fuel and vitrified HLW). The Environmental Protection Agency has specified that vitrification is the best demonstrated available technology for HLW (55 FR 22627). This approach implies that if the behavior of the Pu forms in a repository is the same or better than the commercial spent nuclear fuel or HLW, and if a repository can be licensed for commercial spent nuclear fuel and HLW, then it is possible that the proposed Pu forms could also be disposed in a repository. [Text deleted.] Due to the great amount of data and information available, U-based commercial spent nuclear fuel and vitrified HLW are used for the basis of the comparison.

If the DOE HLW Program changes its approach for disposal of commercial spent nuclear fuel, if the timeframe for acceptance of forms into the program is significantly delayed beyond Pu disposition requirements, or if the Pu immobilized forms or mixed oxide (MOX)-based spent nuclear fuel resulting from Pu disposition alternatives are determined to be unacceptable to a licensed repository, then DOE would analyze the impacts of continued storage of immobilized Pu or MOX-based spent nuclear fuel in a tiered *National Environmental Policy Act* of 1969 (NEPA) document. Simultaneously, DOE will continue its efforts to site and construct a repository that meets the requirements of the NWPA.

This appendix contains a comparative analysis of five Pu forms: (1) immobilized Pu and other radionuclides in borosilicate glass, (2) immobilized Pu and other radionuclides in ceramic disks, (3) boiling water reactor (BWR) MOX-based spent nuclear fuel, (4) pressurized water reactor (PWR) MOX-based spent nuclear fuel, and (5) immobilized Pu and other radionuclides in glass-bonded zeolite (GBZ). The purpose of this feasibility analysis is to compare the performance of these Pu forms against those currently being considered for disposal in a repository. The comparison for these Pu forms is based on information in the *Report on Evaluation of Plutonium Waste Forms For Repository Disposal*. Further, since the NWPA (as amended) identifies Yucca Mountain, Nevada, as the only location for repository site characterization studies, all candidate waste form performance analyses assume the same geological conditions (unsaturated tuff) as that site.

For each alternative, the total number of additional, if any, waste packages that would be added to the approximately 12,000 packages currently envisioned for the first HLW repository is small enough that any changes in emplacement could be accommodated within the design ratings of such a repository.

H.2 GLASS FORM WITH RADIONUCLIDES

The Pu-loaded glass form is assumed to be fabricated in a new facility using borosilicate glass as the vitrified matrix with the radioactive Cs isotope (Cesium-137) mixed in to provide a source of radiation as a barrier to theft and diversion. This PEIS analyzes only gadolinium (Gd) although boron and lithium neutron absorbers present in the borosilicate glass could be supplemented with samarium or other neutron absorbers.

H.2.1 ASSUMPTIONS

Figure H.2.1–1 shows the waste package containing the glass forms. For the purposes of the PEIS analyses, the following assumptions have been made:

- The waste is packaged as shown in Figure H.2.1–1.
- Molten glass is poured into stainless steel canisters to form encased glass logs that are similar to the Defense Waste Processing Facility (DWPF) glass logs and canisters.
- Each transportation cask holds five of these canisters; each disposal waste package holds four of these canisters.

H.2.2 CHARACTERISTICS

Each proposed glass log from a vitrification facility process consists of 1,540 kilograms (kg) (3,387 pounds [lb]) of borosilicate glass in a stainless steel canister containing 84 kg (185 lb) Pu, 1 kg (2.2 lb) Cs-137, and 55 kg (122 lb) Gd. The Gd, together with the boron and lithium in the glass, acts as a neutron absorber. Other than the addition of Pu, Cs, and Gd, the composition of this glass is assumed to be similar to the borosilicate glass candidate waste form in production at the DWPF at Savannah River Site.

H.2.3 COMPARATIVE ANALYSIS

Regulatory. Any waste form that is accepted for disposal in an HLW geologic repository must comply with the provisions of the NWPA, as amended. According to Section 2(12)A of the NWPA, the definition of HLW does not explicitly include Pu loaded into borosilicate glass. However, under Section 2(12)B of the NWPA, the NRC has the authority to classify this waste as HLW through rulemaking. Such rulemaking or clarification in authorizing legislation will be necessary before this waste form can be considered for disposal in an NWPA repository. The final disposal of this waste form will have to conform to the licensing provisions of 10 CFR 60. Further, it is current policy of the DOE not to accept into the first HLW repository any wastes that include components regulated as hazardous under the *Resource Conservation and Recovery Act* (RCRA) (DOE 1995a:6). The absence of any RCRA-regulated hazardous materials in the final glass form would have to be demonstrated prior to acceptance into the HLW repository.

Criticality. The effective neutron multiplication factor (k_{eff}) for the intact glass form, assuming credit for the neutron absorbers during the post-closure period, is calculated to be to less than 0.3, which is well below the 0.95 maximum value of k_{eff} allowed (10 CFR 60).

Thermal. As shown in Figure H.2.3–1, the results of a thermal analysis of a waste package containing four Pu glass logs indicate that the peak temperature reached by the glass package is about 200 degrees Centigrade (°C) (~400 degrees Fahrenheit [°F]), which is within 5 percent of the peak temperature predicted for the glass logs from the DWPF. These predicted temperatures are far lower than, and therefore safely away from, the glass transition temperature of 400 °C (750 °F). Such small differences in temperature and thermal output are unlikely to materially affect the thermal balance of any repository.

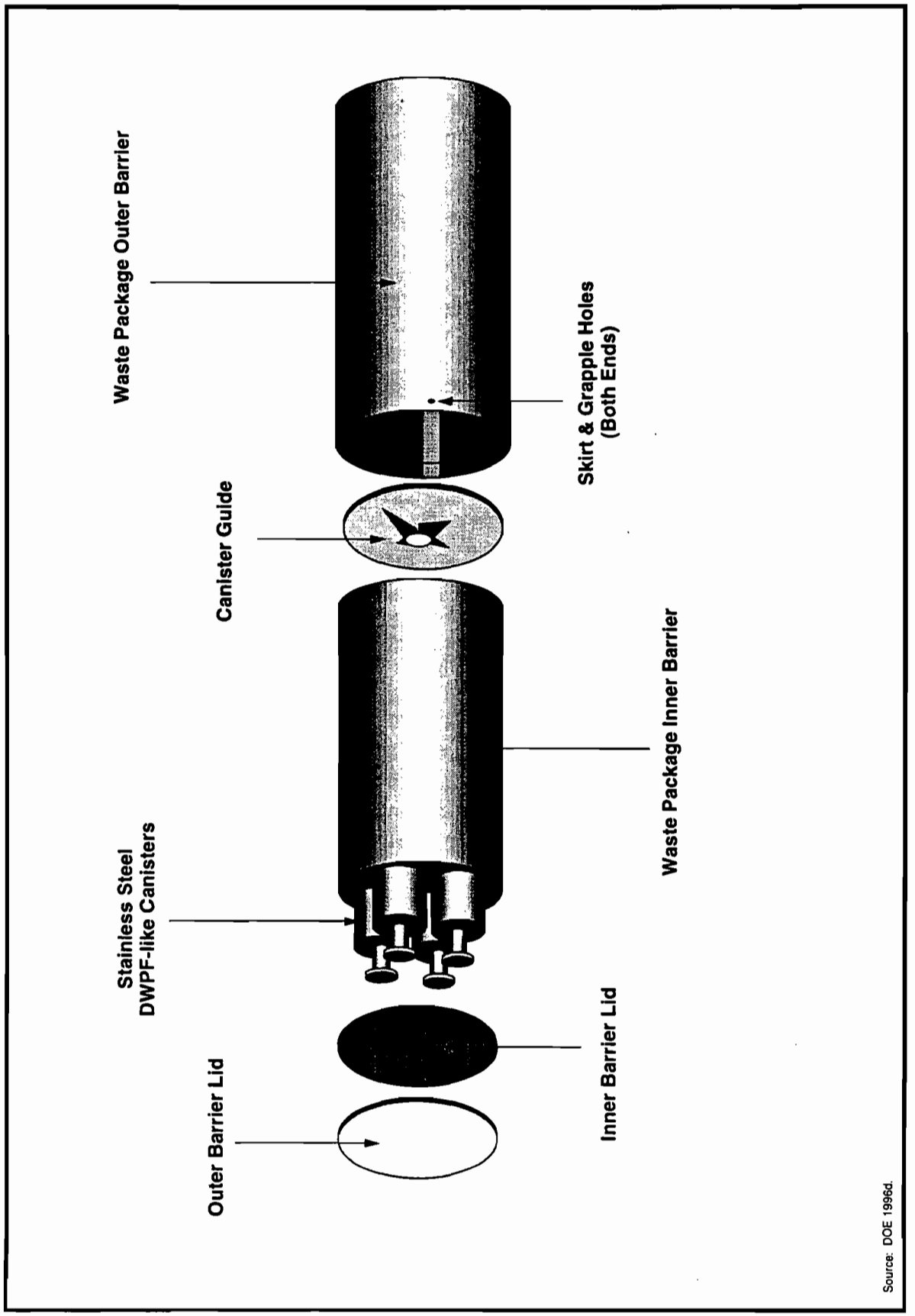


Figure H.2.1–1. Schematic of Waste Package Containing Canisters of Plutonium Immobilized in Glass.

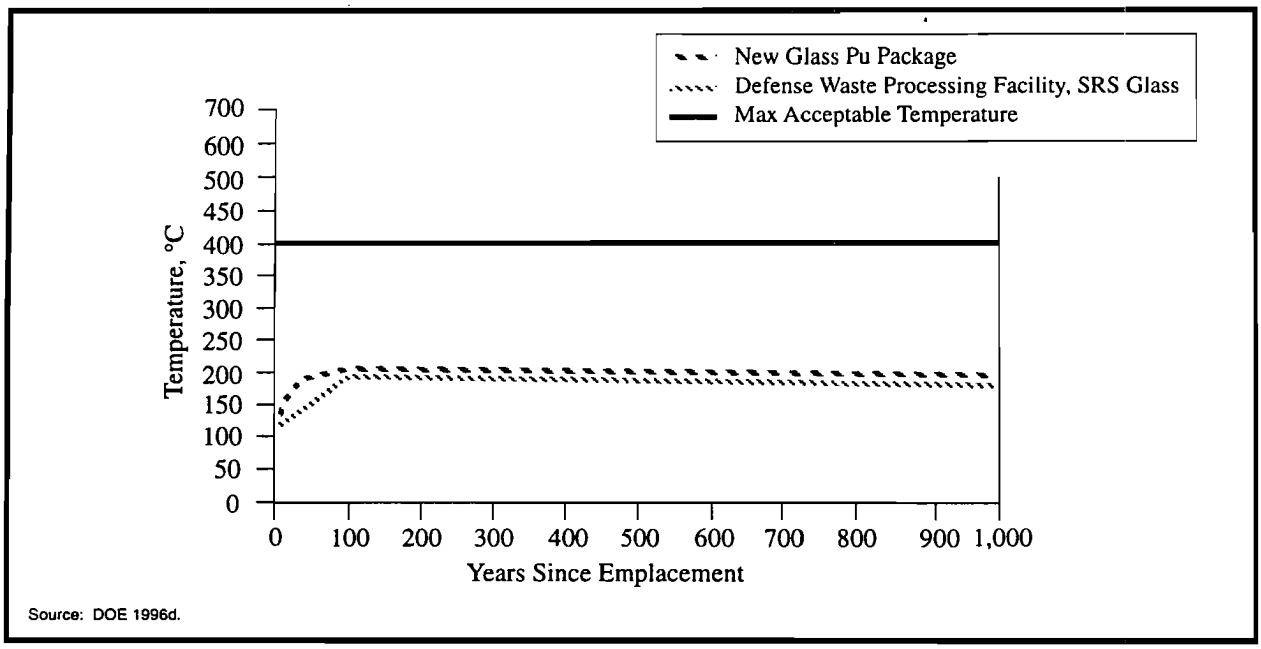


Figure H.2.3–1. Thermal Comparison of Plutonium-Loaded Glass Waste Package Versus Defense Waste Processing Facility Glass Waste Package.

Radiation. A comparison between the DWPF glass and the glass containing Pu shows that the radiation dose at the waste package surface is 81 roentgen equivalent man (rem)/hour (hr) for the DWPF glass compared to 129 rem/hr for the Pu glass. This Pu-glass radiation is above the threshold value for radiolytic corrosion. A 0.4 centimeters (cm) (0.16 inches [in]) additional thickness of the copper-nickel (Cu-Ni) alloy waste package outer barrier would be required to reduce the radiation to an acceptable (100 rad [radiation absorbed dose]/hr) level to protect the waste package from radiolysis-induced corrosion. Additional shielding is also required to protect workers. Doses at a distance of 2 meters (m) (6.6 feet [ft]) from the waste package surface show values of 12.5 rem/hr for the DWPF glass and 25 rem/hr for the Pu glass. For emplacement in the repository, only 5 cm (2 in) of lead thickness and 0.5 cm (0.2 in) of borated polyethylene neutron shielding must be added to the waste package underground transporter to reduce the radiation doses to meet the standard allowable dose of 10 millirem/hr at 2 m (7 ft) from lateral outer surfaces (49 CFR 173.441) to ensure worker protection. An alternative approach to accommodating the higher radiation from the Pu-loaded glass would be to reduce the number of canisters per waste package or the quantity of Cs-137.

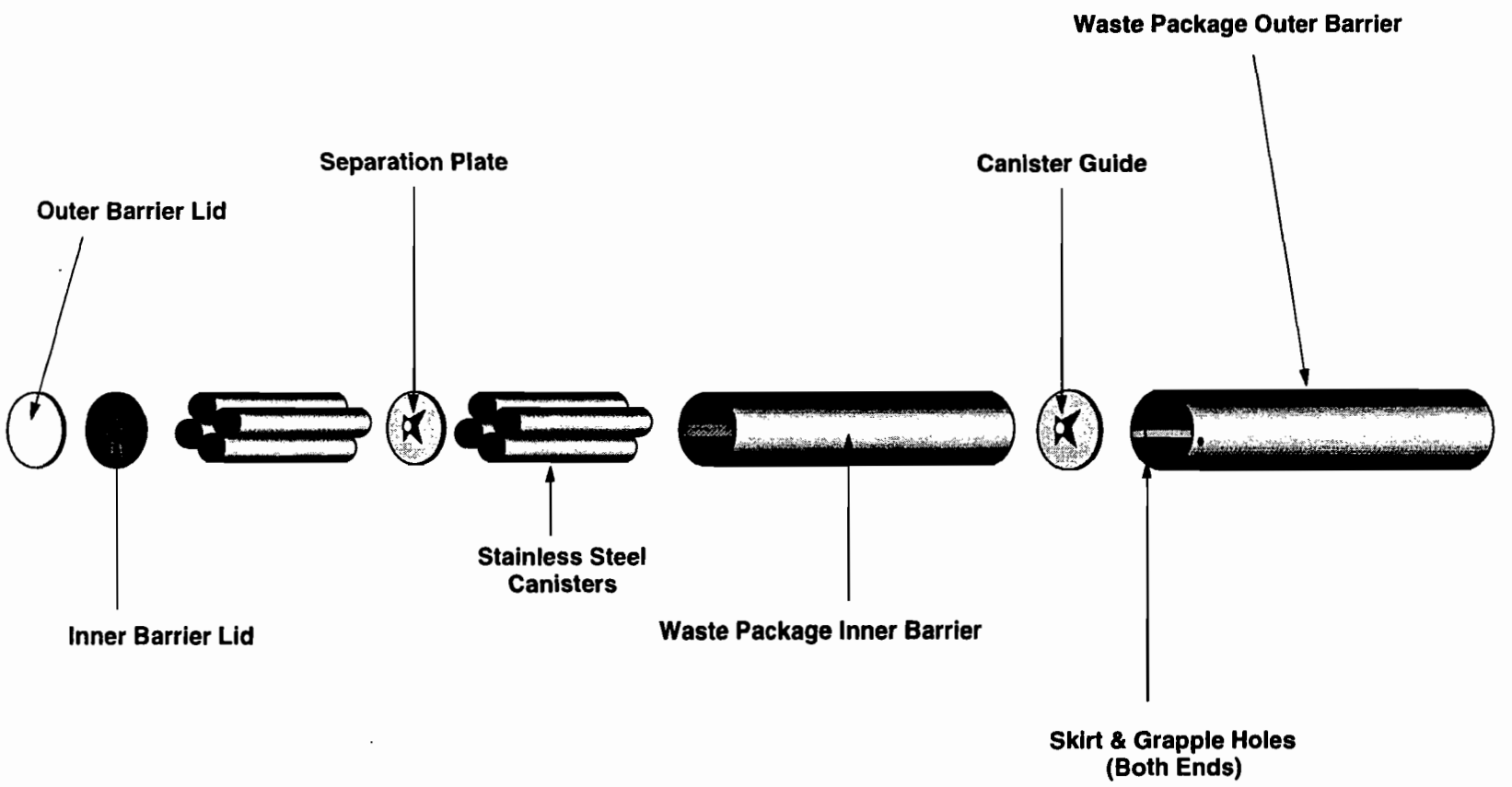
Releases. The peak doses from a repository that contains commercial spent nuclear fuel, vitrified HLW, and Pu immobilized in borosilicate glass are the same as from a repository that contains only commercial spent nuclear fuel and vitrified HLW, for periods up to one million years (DOE 1996d:4-12). These results are to be expected since the quantity of Pu glass is small compared to the quantity of spent nuclear fuel in the repository.

H.3 CERAMIC IMMOBILIZED FORMS WITH RADIONUCLIDES

The Pu-loaded ceramic matrix form is assumed to be fabricated in a new facility. As in the vitrification alternative, Cs-137 is mixed in to provide a source of radiation, and Gd acts as a neutron absorber.

H.3.1 ASSUMPTIONS

Figure H.3.1–1 shows the waste package containing the ceramic forms. For the purposes of the PEIS analyses, the following assumptions have been made:



Source: DOE 1996d.

3037/S&D

Figure H.3.1–1. Schematic of Waste Package Containing Canisters of Plutonium Immobilized in Ceramic.

- The waste is packaged as shown in Figure H.3.1–1.
- Ceramic disks will be stacked inside stainless steel canisters. These canisters are similar to the DWPF canisters.
- Each disposal waste package holds eight of these canisters.

H.3.2 CHARACTERISTICS

Each canister of the proposed waste form contains 20 ceramic disks; each disk is approximately 30 cm (12 in) in diameter, and 10 cm (4 in) thick. Each disk has stainless steel plates added to the top and bottom, and a stainless steel shell around the curved surface. The disks are stacked vertically in a stainless steel canister approximately 2.5 m (8 ft) long, and 35 cm (14 in) in diameter. The ceramic disks consist of zirconolite, hollandite, and rutile. For each disk, the zirconolite incorporates 2.6 kg (6.0 lb) of Gd, and the hollandite incorporates 4.0 kg (9.0 lb) of Pu and 0.07 kg (2.0 oz) of Cs-137. The space surrounding the stack of disks inside the canister is filled with titanium oxide powder.

H.3.3 COMPARATIVE ANALYSIS

Regulatory. Any waste form that is accepted for disposal in an HLW geologic repository must comply with the provisions of the NWPA, as amended. According to Section 2(12)A of the NWPA, the definition of HLW does not explicitly include Pu loaded into a ceramic matrix. However, under Section 2(12)B of the NWPA, the NRC has the authority to classify this waste as HLW through rulemaking. Such rulemaking or clarification in authorizing legislation would be necessary before this waste form can be considered for disposal in an NWPA repository. The final disposal of this waste form will have to conform to the licensing provisions of 10 *Code of Federal Regulations* (CFR) 60. Further, it is current policy of the DOE not to accept into the first HLW repository any wastes which include components regulated as hazardous under RCRA (DOE 1995a:6). The absence of any RCRA-regulated hazardous materials in the final ceramic form would have to be demonstrated prior to acceptance into the HLW repository.

Criticality. Preliminary criticality calculations for the intact ceramic waste package, under dry or flooded conditions, and assuming credit for the Gd neutron absorber, yields k_{eff} values of less than 0.7, which is below the 0.95 maximum value of k_{eff} allowed (10 CFR 60).

Thermal. As shown in Figure H.3.3–1, the results of a thermal analysis of Pu-loaded ceramic waste packages shows that peak temperatures are around 200 °C (~400 °F), declining as a function of time. Ceramic, unlike glass, does not have a transition temperature because it is a crystalline material. The lowest melting point temperature for the oxides of this ceramic material is around 1800 °C (3270 °F). Therefore, the calculated peak temperatures are unlikely to affect the ceramic matrix. Further, the temperature differences between the ceramic waste package and the DWPF HLW glass waste package are negligibly small.

Radiation. A comparison between the DWPF HLW glass and the Pu-loaded ceramic shows that the radiation dose at the waste package surface is 81 rem/hr for the DWPF glass compared to 309 rem/hr for the ceramic. The radiation level for the ceramic form is above the threshold value for radiolytic corrosion. Consequently, a 1-cm (0.4-in) additional thickness of the Cu-Ni alloy waste package outer barrier would be required to reduce the radiation to an acceptable level (100 rad/hr) to protect the waste package from radiolytic corrosion. Additional shielding is also required to protect workers. Doses at 2 m (6.6 ft) from the package surface show values of 12.5 rem/hr for the DWPF glass and 56.4 rem/hr for the ceramic. For emplacement in a repository, only 5 cm (2 in) of lead thickness and 0.5 cm (0.2 in) of borated polyethylene neutron shielding must be added to the waste package underground transporter to reduce the radiation doses to meet the standard allowable dose of 10 mrem/hr at 2 m (7 ft) from lateral surfaces (49 CFR 173.441) to ensure worker protection. An alternative approach to

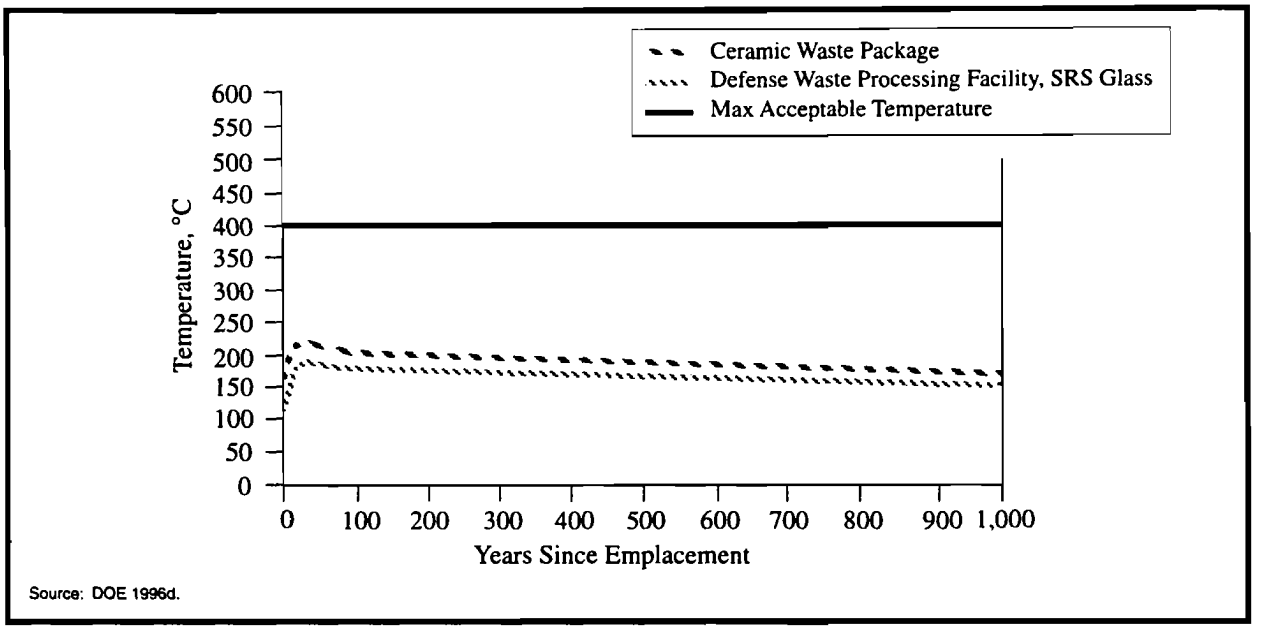


Figure H.3.3–1. Thermal Comparison of Plutonium-Loaded Ceramic Waste Package Versus Defense Waste Processing Facility Glass Waste Package.

accommodating the higher radiation fields from the Pu-loaded ceramic would be to reduce either the number of canisters per package or the quantity of Cs-137.

Releases. The peak doses from a repository that contains commercial spent nuclear fuel, vitrified HLW, and Pu immobilized in ceramic are the same as from a repository that contains only commercial spent nuclear fuel and vitrified HLW, for periods up to one million years. The difference in dose rates is insignificant between these two cases (DOE 1996d:5-12). These results are to be expected since the quantity of Pu in ceramic is small compared to the quantity of spent nuclear fuel in the repository.

H.4 BOILING WATER REACTOR—MIXED OXIDE BURNING REACTOR SPENT NUCLEAR FUEL FORM

Boiling water reactors are used in existing commercial power generation; therefore, the BWR form of the MOX spent nuclear fuel could be the output product from both the Existing LWR Alternative and the Partially Completed LWR Alternative if the latter is consistent with the BWR design. The performance of this MOX spent fuel is compared to the corresponding commercial BWR uranium-based boiling water reactors spent nuclear fuel.

H.4.1 ASSUMPTIONS

For the purposes of the PEIS analyses, the following assumptions have been made:

- The Pu will be fabricated into MOX nuclear reactor fuel and used for power generation in four boiling water reactors and allowed to cool at the reactor site(s) in the spent fuel pools for at least 10 years before shipment to a repository.

- The spent fuel will be emplaced in large (40 BWR assembly) waste packages for emplacement in a repository.

H.4.2 CHARACTERISTICS

The MOX spent fuel assembly from existing BWRs will have the following characteristics: (1) total Pu of 3.4 kg (7.5 lb), (2) Pu-239 to total Pu ratio of 0.4, (3) total heavy metal content of 172 kg (379 lbs), and (4) burn up of 37.6 gigawatt-days (GWd)/ton (t) of heavy metal. Radiation is analyzed using neutron and gamma source strengths by energy group.

H.4.3 COMPARATIVE ANALYSIS

Regulatory. An HLW repository, if approved under the provisions of the NWPA, would serve primarily as the disposal site for commercial spent nuclear fuel and defense-generated HLW. The MOX spent fuel that would be generated by this alternative falls within the definition of "spent nuclear fuel" per Section 2(23) of the NWPA and could, therefore, be considered a candidate for disposal in an NWPA repository. Licensing for the disposal of this MOX spent fuel form must follow the provisions of 10 CFR 60.

Criticality. Figure H.4.3–1 compares the results of the criticality analyses for a waste package containing all MOX spent fuel with one containing U-based spent fuel. The k_{eff} for the MOX spent fuel is below that of U-based fuels and well below the 0.95 maximum value allowed for k_{eff} (10 CFR 60).

Thermal. Figure H.4.3–2 shows the results of a thermal analysis of the MOX spent fuel element in a fully loaded, emplaced waste package. The peak cladding temperature is below the 350 °C (662 °F) limit required to maintain cladding integrity. Calculations also indicate that for the first 100 years the MOX cladding temperature continues to be lower than that of the corresponding U-based spent fuel. The slightly higher temperatures beyond the 100 years are so small as to have a negligible affect on the thermal balance of any repository.

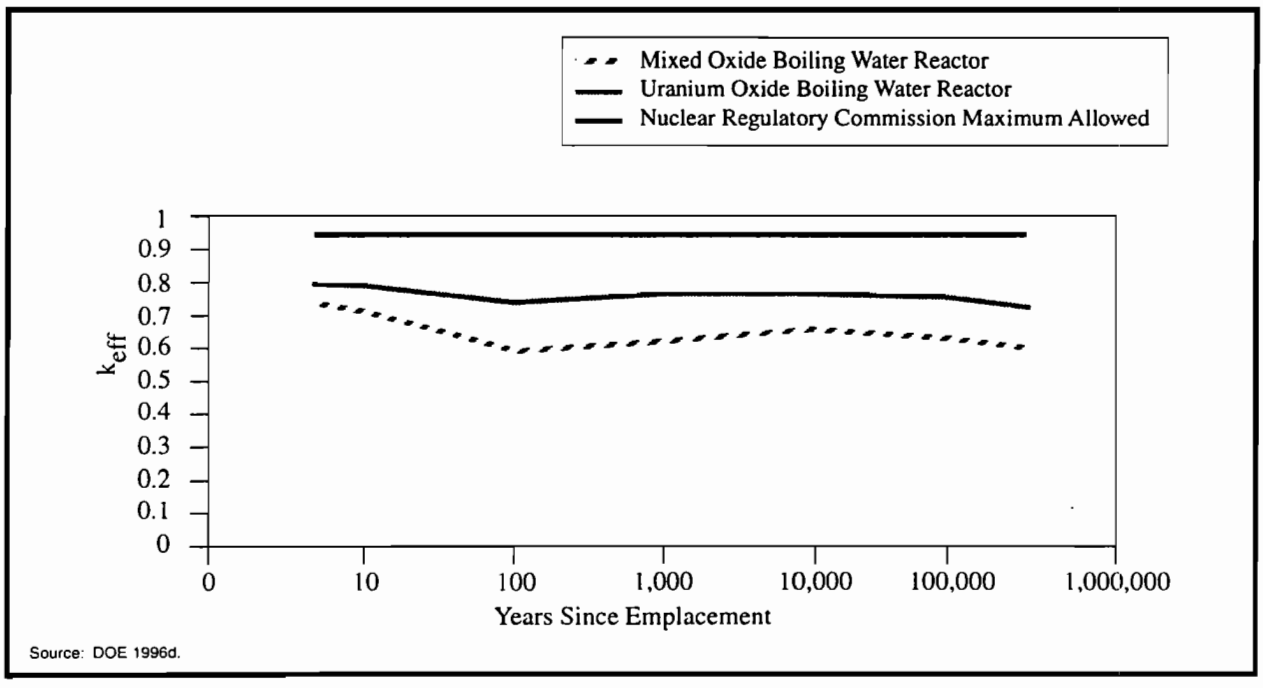


Figure H.4.3–1. Effective Multiplication Factor (k_{eff}) of a Boiling Water Reactor Spent Fuel Waste Package.

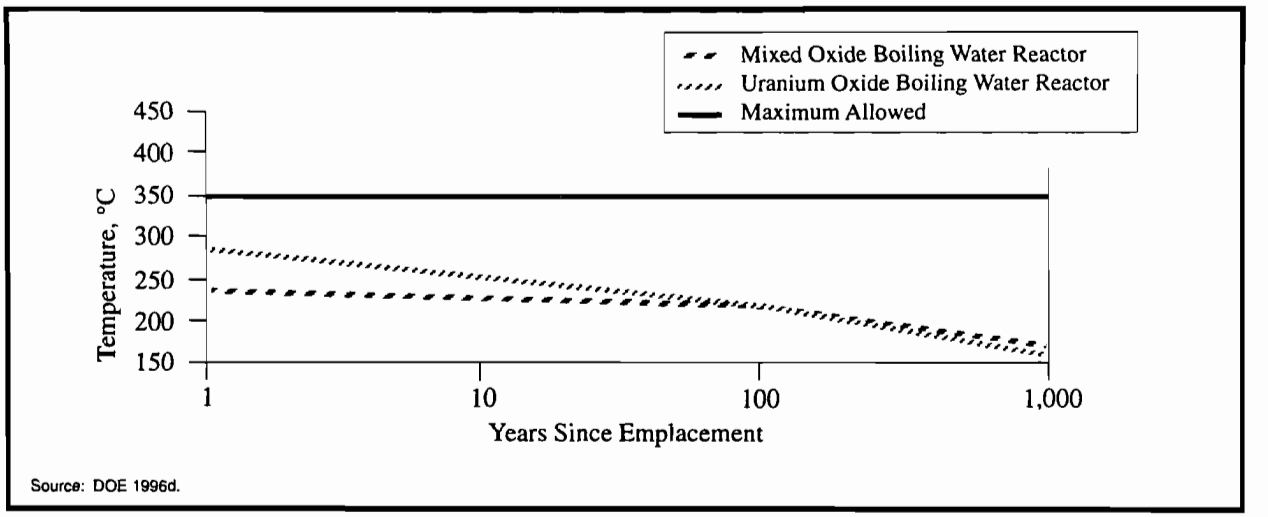


Figure H.4.3–2. Thermal Comparison of Peak Cladding Temperature of Boiling Water Reactor Fuel Element Versus Uranium-Based Reactor Fuel Element.

Radiation. Radiation calculations predict that the unshielded dose rates at a distance of 2 m (6.6 ft) are slightly higher for the waste packages containing MOX fuel than for those containing uranium-based fuels. The gamma radiation dose for the MOX fuel is 5 rem/hr versus 4 rem/hr for the U-based fuel. The neutron radiation dose is 1.54 rem/hr for the MOX as versus to 0.8 rem/hr for the uranium fuel. The higher radiation doses can be accommodated by increasing the transporter shielding thickness by 0.125 cm (0.05 in) of lead for the gamma radiation, and 1.25 cm (0.5 in) of boron-polyethylene for the neutron radiation.

Releases. The calculated doses for just the waste packages of MOX-based spent fuel are 100 times less than that for a repository that contains both MOX and (U-based) commercial spent nuclear fuels (DOE 1996d:3-8). These results support the conclusion that the performance of the repository is dominated by the presence of (U-based) commercial spent nuclear fuel and is expected since the quantity MOX-based spent nuclear fuel is small compared to the larger quantity of commercial spent nuclear fuel in the repository.

H.5 PRESSURIZED WATER REACTOR—MIXED OXIDE BURNING REACTOR SPENT NUCLEAR FUEL FORM

For the Evolutionary LWR Alternative, a PWR could be the design for burning MOX fuel. PWRs are used in existing commercial power plants; therefore, the PWR form of the spent MOX nuclear fuel could be the output product from the Evolutionary LWR Alternative, Existing LWR Alternative, and the Partially Completed LWR Alternative if the latter reactors are consistent with the PWR design. The performance of this MOX spent nuclear fuel is compared to the corresponding U-based PWR spent nuclear fuel.

H.5.1 ASSUMPTIONS

For the purposes of the PEIS analyses, the following assumptions have been made:

- The Pu will be fabricated into MOX nuclear fuel and used for power generation in two PWRs and allowed to cool at the reactor site(s) in the spent fuel pools for at least 10 years before shipment to a repository.

- The spent fuel will be emplaced in large waste packages for emplacement in a repository.

H.5.2 CHARACTERISTICS

The MOX spent fuel assembly from an evolutionary PWR will have the following characteristics: (1) total Pu of 20 kg (44 lb), (2) Pu-239 to total Pu ratio of 0.6, (3) total heavy metal content of 410 kg (900 lbs), and (4) burn up of 43 GWd/t of heavy metal. Radiation is analyzed using neutron and gamma source strengths by energy group.

H.5.3 COMPARATIVE ANALYSIS

Regulatory. An HLW repository, if approved under the provisions of the NWPA, would serve primarily as the disposal site for commercial and DOE-owned spent nuclear fuel and HLW. The MOX spent fuel that would be generated by this alternative falls within the definition of "spent nuclear fuel" per Section 2(23) of the NWPA and could, therefore, be considered a candidate for disposal in an NWPA repository. Licensing for the disposal of this MOX spent fuel form must follow the provisions of 10 CFR 60.

Criticality. Calculations for a MOX PWR spent fuel waste package show that to maintain a value below the 0.95 maximum value allowed for k_{eff} (10 CFR 60), the waste package can hold only four assemblies. This calculation assumed no additional criticality control technology. Should such technology be applied (for example, disposable control rod assemblies were added to the waste packages) calculations show that 21 assemblies could be loaded in each waste package. For either the 4 or 21 assemblies/waste package case, the k_{eff} value is expected to decline with time in a manner similar to that of the BWR spent fuel waste package as shown in Figure H.4.3–1.

Thermal. Figure H.5.3–1 shows the results of a thermal analysis of the MOX PWR spent fuel. The peak cladding temperature is below the 350 °C (662 °F) limit required to maintain cladding integrity. For the first 100 years the temperature also remains lower than that of the corresponding U-based spent fuel. The additional heat from all the spent nuclear fuel packages produced by the PWRs would be so small as to have a negligible affect on the thermal balance of any repository.

Radiation. Radiation calculations for the 21-assembly MOX PWR waste package shows that the higher dose rates from the MOX package (compared to the package containing U-based spent fuel) can be easily accommodated by increasing the transporter shielding thickness by 0.4 cm (0.16 in) of lead for the gamma radiation, and 1.25 cm (0.5 in) of boron-polyethylene for the neutron radiation. The shielding thickness requirements for a four-assembly package will be less than these values.

Releases. The calculated doses for just the waste packages of MOX-based spent fuel are 100 times less than that for a repository that contains both MOX and (U-based) commercial spent nuclear fuel (DOE 1996d:6-7). These results support the conclusion that the performance of the repository is dominated by the presence of (U-based) commercial spent nuclear fuel and is expected since the quantity of MOX-based spent fuel is small compared to the larger quantity of commercial spent fuel in the repository.

H.6 GLASS-BONDED ZEOLITE FORM

The Pu-loaded GBZ form is assumed to be fabricated in an electrometallurgical treatment process and has characteristics for long term disposability in a repository that are similar to the borosilicate glass produced in the DWPF (DOE 1996d:4-1). The GBZ waste form constitutes another immobilization alternative which would require disposal in a repository.

H.6.1 ASSUMPTIONS

For the purposes of the PEIS analyses, the following assumptions have been made:

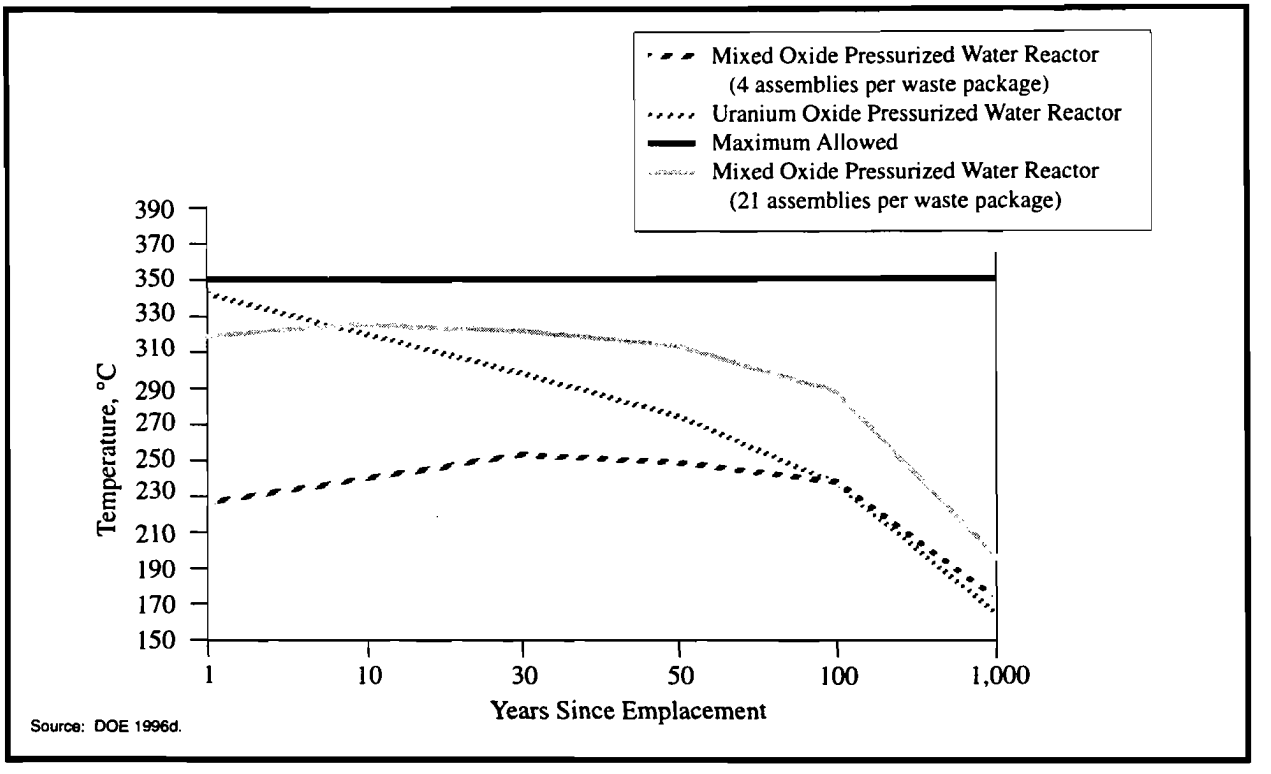


Figure H.5.3–1. Thermal Comparison of Peak Cladding Temperature of Pressurized Water Reactor Fuel Element Versus Uranium-Based Reactor Fuel Element.

- The waste form is packaged in DWPF-like canisters.
- Each transportation cask holds five of these canisters; each disposal waste package holds four of these canisters.

H.6.2 CHARACTERISTICS

The GBZ will be prepared by sorbing a molten chloride Pu salt on an anhydrous zeolite, which is then blended with a glass frit. The whole mixture is heated in a mold to above the glass transition temperature and pressed to bond the zeolite to the glass. The chemical constituents of the waste form are as follows: 52 kg (114 lbs) of Pu, 21 kg (46 lbs) of Gd, 5 kg (11 lbs) of Cs, 364 kg (800 lbs) of zeolite, and 520 kg (1,144 lbs) of borosilicate glass. The remainder is made up of barium, lithium, potassium, sodium, and chlorides.

H.6.3 COMPARATIVE ANALYSIS

Regulatory. Any waste form that is accepted for disposal in an HLW geologic repository must comply with the provisions of the NWPA, as amended. According to Section 2(12)A of the NWPA, the definition of HLW does not explicitly include Pu loaded into GBZ. However, under Section 2(12)B of the NWPA, the NRC has the authority to classify this waste as HLW through rulemaking. Such rulemaking or clarification in authorizing legislation will be necessary before this waste form can be considered for disposal in an NWPA repository. The final disposal of this waste form will have to conform to the licensing provisions of 10 CFR 60. Further, it is current policy of the DOE not to accept into the first HLW repository any wastes that include components regulated as hazardous under RCRA (DOE 1995a:6). The absence of any RCRA-regulated hazardous materials in the final GBZ form would have to be demonstrated prior to acceptance into the HLW repository.

Criticality. Preliminary criticality calculations show the Pu-loaded GBZ in a dry, intact configuration has a k_{eff} of less than 0.2, which is less than the borosilicate glass form primarily because of the lower total Pu content of each waste package containing the GBZ. The k_{eff} values for the GBZ under flooded conditions are less than half the 0.3 value (0.13) calculated for the borosilicate glass form and well below the 0.95 maximum value allowed for k_{eff} (10 CFR 60).

Thermal. Because the Pu concentration in a waste package containing Pu-loaded GBZ canisters is 80 percent of the Pu concentration in a package containing Pu-loaded borosilicate glass, and because the peak temperature reached by borosilicate glass is below the 400 °C (750 °F) glass transition value, the peak temperature for the GBZ is also expected to be below the 400 °C (750 °F) glass transition temperature. More specifically, the lower Pu content of the GBZ means that the heat generation at 40 years and beyond would be much smaller than for the Pu-loaded borosilicate glass.

Radiation. A comparison between the DWPF HLW glass and the Pu-loaded GBZ shows that the radiation dose at the waste package surface is 81 rem/hr for the DWPF glass compared to 120 rem/hr for the Pu-loaded GBZ. Since the radiation level for GBZ is above the threshold value of 100 rads/hr for radiolytic corrosion, the waste package outer barrier thickness would need to be increased by 0.3 cm (0.11 in). Additional shielding is also required to protect workers. The dose rate at 2 m (6.6 ft) from the waste package is 23 rem/hr for the GBZ versus 12.5 rem/hr for DWPF glass. As in the case for the Pu-loaded borosilicate glass form, the addition of 5 cm (2 in) of lead shielding to the underground transporter would reduce the radiation doses to meet the standard allowable dose of 10 mrem/hr at 2 m (6.6 ft) from lateral outer surfaces (49 CFR 173.441) to ensure worker protection.

Releases. The peak doses from a repository that contains commercial spent nuclear fuel, vitrified HLW, and Pu immobilized in GBZ are the same as from a repository that contains only commercial spent nuclear fuel and vitrified HLW, for periods up to 1 million years (DOE 1996d:7-9). These results are to be expected since the quantity of Pu in GBZ is small compared to the quantity of spent nuclear fuel in the repository.

Appendix I
Changes in Canadian Deuterium Uranium Reactor Operations

Ontario Hydro operates 20 Canadian Deuterium Uranium (CANDU) reactors capable of using mixed oxide (MOX) at five nuclear generating stations in the Province of Ontario. Eight of these units are located at the Bruce-A and Bruce-B Nuclear Generating Stations, a 930-hectare (2,300-acre) site on Lake Huron about 300 kilometers (186 miles) northeast of Detroit, Michigan. The Bruce-A Nuclear Generating Station, which contains four 769-megawatt electric reactors, a common powerhouse with four turbine generators, a heavy water plant, a process steam transformer plant, a central services area, pumphouses, standby generators, and other support facilities, is used as the reference site for the disposition alternative evaluation. One or up to four of these units could be used for Plutonium (Pu) disposition for this alternative. The reference reactor MOX fuel cycle, adapting the standard CANDU fuel bundle in the four reactors, would dispose of approximately 2 metric tons/year (t/yr) of Pu (2.2 short tons [tons]/yr) and eliminate the mining and refining of approximately 6,000 t/yr (6,600 tons/yr) of uranium ore. The use of the CANDU reactors would be subject to the approval, policies, and regulations of the Canadian Federal and Provincial Governments. The fuel cycle is depicted in Figure I–1.

An alternate fuel bundle design using uranium fuel (the CANFLEX fuel bundle), which is currently undergoing reactor qualification, might be used. This fuel bundle has smaller diameter elements in the outer rings that would operate at a lower linear power rating, permitting higher Pu concentrations. Both designs have essentially the same Pu disposition capacity. The design is expected to reduce the number of fuel bundles and waste volumes by half.

The Bruce-A Nuclear Generating Station was selected as the reference plant for the following reasons:

- The reactor is designed without thermal neutron absorbing control rods to flatten power distribution in the central region of the core, a desirable attribute relative to thermal power margins. MOX fuel would perform in the same manner as natural uranium fuel in flattening the power distribution.

- The site is a base-load station that will maximize fuel consumption since reactors operate continually at or near their full load capability.

- The site is remote from population centers, yet relatively close to U.S.-Canadian border crossings for the shipment of MOX fuel from the United States.

- The site has current International Atomic Energy Agency approved safeguards and a Perimeter Intrusion Detection and Assessment System.

Reactor. Instead of a single large pressure vessel, the reference CANDU reactor has a horizontal, cylindrical, heavy water-filled, calandria tank containing 480 fuel channel assemblies (also referred to as tubes) and reactivity control units. Replacement of these tubes, "retubing," corresponds to core replacement in other reactors. The heavy water is the neutron moderator and reflector. This entire assembly is contained in the light water-filled shield tank to form an integral structure that provides operational and shutdown shielding.

Each fuel channel assembly consists of a zirconium-niobium alloy pressure tube contained within a zircaloy-2 calandria tube that provides a gas-filled, thermally insulated annulus separating the high pressure and high temperature heavy water coolant in the pressure tube from the low pressure and low temperature heavy water moderator in the calandria. Reactor neutron and gamma flux is attenuated through a latched steel shield plug mechanism inside the end fitting.

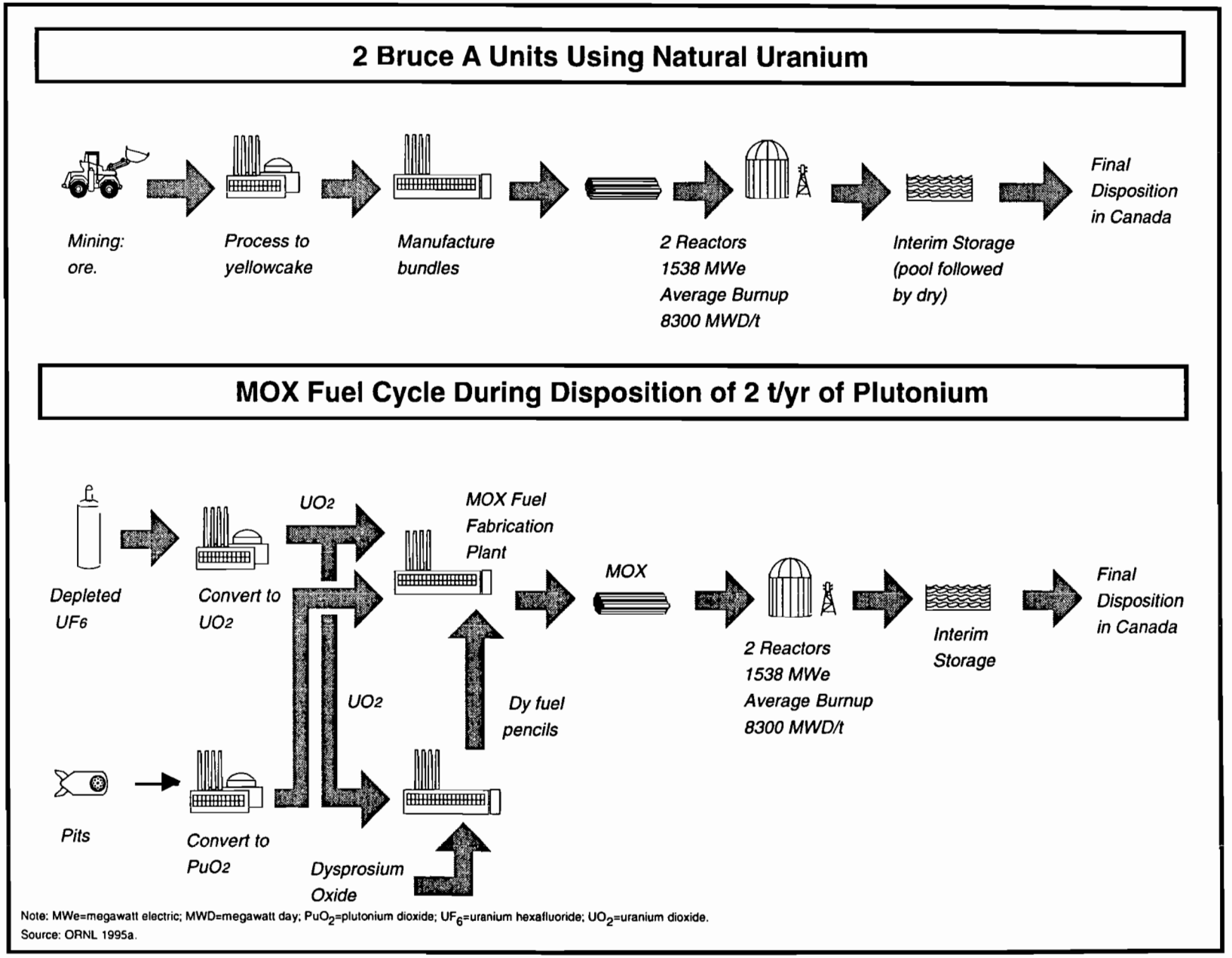


Figure I–1. Mixed Oxide Fuel Cycle.

Heat is removed by circulating heavy water coolant from the fuel channels to the steam generator, where it is transferred to the light water side. This system includes circulating pumps, headers, feeder pipes, the primary side of the steam generators, and preheaters. During operation, pressure is maintained by steam bleed valves connected to the pressurizer and immersion heaters within the pressurizer vessel.

The heavy water moderator circulates through the calandria and is cooled by heat exchangers. Moderator chemistry is maintained by the ion-exchange columns of the moderator purification circuit. Helium is the moderator cover gas.

Fourteen compartments within the reactor function as light water zone control units. These zones contain volumes of water, which are used to control reactor power. Self-powered, in-core neutron flux detectors located in each zone, along with channel thermal measurements, are used for power measurements by the reactor control system. On-power refueling and soluble neutron-absorbing material in the heavy water provide long-term reactivity control.

Steam from the secondary side of the steam generators is transferred to steam drums where it is routed to turbine generators. The turbines are tandem-compound, single-shaft machines that drive electrical generators. Each turbine has a double-flow, high-pressure chamber that discharges to a steam reheater that raises steam temperature for three double-flow, low- pressure chambers.

Fuel Handling and Storage. CANDU reactors can be refueled on-line. Operator consoles remotely control the fueling operation. A fueling duct traversed by two sets of transport trolley rails is used to move fresh MOX fuel to each reactor. In their loading area, new fuel bundles are placed in fueling machines that then pass through the containment wall port to fueling machine heads. At the reactor, the loading head is aligned with, and locks onto, the selected fuel channel end fitting. The loading head inserts new fuel bundles two at a time. At the other end of that channel, fuel bundles are displaced into a spent fuel head. After the required number of bundles has been placed in the channel the loading head is unlocked. This procedure is repeated until the designated channels are fueled. The irradiated fuel is discharged to the primary irradiated fuel storage bay. The spent fuel is stored here for a minimum of 6 months before it is transferred to the secondary irradiated fuel storage bay. The primary irradiated fuel storage bay can store 4 reactor years of fuel at an 80-percent capacity factor, while the storage capacity of the secondary bay is approximately 64 reactor years.

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Appendix J
Applicable Laws, Regulations, and Other Requirements

Compliance With Statutes, Regulations, and Other Associated Orders

Appendix J identifies the compliance requirements associated with the proposed action as specified by the major Federal and State Environment, Safety, and Health (ES&H) statutes, regulations, and orders.

Introduction and Purpose

This appendix provides enough information concerning the environmental standards and statutory requirements that impact the various alternatives for long-term storage and disposition of weapons-usable fissile materials to help make programmatic-level decisions. These statutes and regulations provide the standard with which the ability of candidate sites to meet ES&H requirements and the ability to obtain required Federal and State permits and licenses necessary to implement such decisions may be calculated. This appendix first provides an historical background on environmental protection at nuclear weapons production facilities. It then presents some of the more important requirements associated with the proposed action by identifying the applicable ES&H statutes, regulations, and orders. These are found in Federal and State statutes, regulations, permits, and approvals, as well as in Executive and Department of Energy (DOE) Orders. The remainder of this appendix explains the concept of shared Federal and State enforcement and summarizes compliance with occupational safety and health and environmental justice.

Compliance with the applicable requirements of each of the major ES&H statutes, regulations, and orders identified would allow DOE to construct and operate long-term storage and disposition facilities to meet such requirements. Sites have been selected for analysis as long-term storage locations. In contrast, since some of the proposed disposition alternatives are currently not tied to any one particular location, a "generic" site will be used for analysis. To be environmentally sound, programmatic decisions must also address the ES&H planning considerations described in Section 3.3 of the *Nuclear Weapons Complex Reconfiguration Study* (DOE/DP-0083). These considerations must also be met in order for the long-term storage and disposition alternatives to meet future ES&H requirements and to accomplish the mission in a timely and cost-effective manner.

Background

Since the majority of the past Complex facilities were constructed in the 1940s and 1950s, before the advent of today's environmental and worker health requirements, safety and the ability to satisfy national security requirements played the dominant roles in the design and operation of major industrial plants. However, with the emergence of an awareness of environmental and health-related issues and the enactment of environmental and worker health programs, DOE shifted a great deal of its resources into programs designed to achieve compliance with all applicable Federal, State, and local ES&H requirements. Today, many government agencies at the Federal, State, and local levels have regulatory authority over DOE's facility operations. DOE has entered into enforceable compliance agreements with the regulators at most of its facilities. These agreements detail specific programs, funding levels, and schedules for achieving compliance with applicable ES&H statutory and regulatory requirements. Because most of these agreements are constantly changing as subject agreements are completed, eliminated, or revised, a list has not been compiled for this programmatic environmental impact statement (PEIS).

All newly constructed and modified facilities must comply with the increasing number and complexity of environmental regulations. It is difficult to make facilities that are more than 40 years old comply quickly with constantly changing requirements. These older facilities generally do not meet all current standards for seismic

design, fire protection, and environmental protection (for example, air emissions, liquid effluents, and the management of solid and hazardous wastes). However, these facilities would be modernized to meet all applicable ES&H requirements now and into the 21st century, and a system would be developed to adequately manage the wastes generated by these facilities regardless of the proposed action addressed in this PEIS.

Environmental Statutes, Orders, and Agreements

The *Atomic Energy Act* (AEA) of 1954 authorizes DOE to establish standards to protect health and minimize dangers to life or property with respect to activities under its jurisdiction. The Nuclear Regulatory Commission (NRC) is charged under the AEA and the *Energy Reorganization Act* of 1974 with jurisdiction over commercial reactor construction and operation. NRC also licenses and regulates the possession, use, transportation, and disposal of radioactive materials, including wastes. NRC and Federal agencies such as the Department of Transportation also periodically review and revise their regulations to bring them generally to the same level as International Atomic Energy Agency regulations (Safety Series No. 6, revised 1990). This agency, under the United Nations, establishes standards for radioactive materials transportation. The Environmental Protection Agency (EPA), under authority of the AEA, has set radiation protection standards such as *Environmental Radiation Protection Standards for Nuclear Power Operations* (40 CFR 190). Most environmental regulations can be found under 40 Code of Federal Regulations (CFR). Because of their length, and for ease of reading, all tables in this chapter are presented consecutively at the end of the text. Table J–1 lists the applicable Federal environmental statutes, regulations, and Executive Orders, and also identifies the associated permit, approval, and consultation requirements generally required to implement an alternative for long term storage or disposition. Except for limited Presidential exemptions, Federal agencies must comply with all applicable provisions of Federal environmental statutes and regulations, in addition to all applicable State and local requirements. DOE is committed to complying fully with all applicable environmental statutes, regulatory requirements, and Executive and internal orders. Table J–2 lists the potential requirements imposed by the major State environmental statutes and regulations applicable to this predecisional PEIS. These requirements apply to Federal activities within the jurisdiction of the enforcing authority. Table J–2 identifies the permits, approvals, and consultations generally required to implement an alternative for long-term storage or disposition in accordance with State statutes and regulations. Table J–3 lists selected DOE ES&H Orders that apply to all sites, but which may affect each site differently. Table J–4 lists applicable NRC guidelines for the processing, use, transportation, and disposal of radioactive materials, including water.

Federal and State Environmental Enforcement

Some environmental regulatory programs are enforced through review, approval, and permitting requirements that attempt to minimize the negative impact of potential pollution sources' releases to the environment by limiting activities to established standards. Federal and State agencies share environmental regulatory authority over DOE's facility operations when Federal legislation delegates permitting or review authority to qualifying States. Some examples are the National Emission Standards for Hazardous Air Pollutants and the Prevention of Significant Deterioration under the *Clean Air Act;* the Water Quality Standards and the National Pollutant Discharge Elimination System under the *Clean Water Act;* the Hazardous Waste Programs under *Resource Conservation and Recovery Act* (RCRA); and the Drinking Water and Underground Injection Control Programs under the *Safe Drinking Water Act*. When Federal legislation allows enforcement authority to be delegated, States must set standards equal to or more stringent than those required by Federal law to obtain such authority. However, when Federal legislation does not allow enforcement authority to be delegated to the States (for example, the *Toxic Substance Control Act*), the standards are administered and enforced solely by the Federal Government.

Under various Federal environmental statutes (Table J–1), EPA may delegate the implementation and execution of the laws' various provisions to States with approved programs that are at least as stringent as the minimum

Federal requirements contained in the laws and EPA regulations. Table J–2 lists many of the States' laws and regulations, including provisions that are more stringent than the minimum requirements. In addition, the *Federal Facility Compliance Act* of 1992 waives sovereign immunity from the enforcement of RCRA at Federal facilities and thereby gives States the authority to assess fines and penalties under certain conditions.

Compliance with Occupational Safety and Health Requirements

The health and safety of all workers associated with the long-term storage and disposition alternatives is a primary consideration in this PEIS. A comprehensive nuclear and occupational safety and health initiative was announced by the Secretary on May 5, 1993, entailing closer consultation with the Occupational Safety and Health Administration (OSHA) regarding regulation of workers' safety and health at DOE's contractor-operated facilities. Regulation of workers', health and safety at DOE's contractor-operated facilities will gradually shift from DOE to OSHA. The *Occupational Safety and Health Act* of 1970, (Public Law 91-596) establishes Federal requirements for assuring occupational safety and health protection for employees. DOE's facilities also comply with the *Emergency Planning and Community Right-To-Know Act* (42 USC 11001), which requires facilities to report the release of extremely hazardous substances and other specified chemicals, provide Material Safety Data Sheets or lists thereof, and provide estimates of the amounts of hazardous chemicals onsite. The reporting and emergency preparedness requirements are designed to protect both individuals and communities.

Workplace Safety. Operations at all DOE sites expose workers to occupational hazards during the normal conduct of their work activities. Occupational safety and health training is provided for all employees at DOE facilities and includes specialized job safety and health training appropriate to the work performed. Such training also includes informing employees of their rights and responsibilities under the *Occupational Safety and Health Act* of 1970; Executive Order 12196, which established OSHA Federal Agency Standards; 29 CFR 1960, The OSHA Federal Agency Standards, which describes the safety and health programs that Federal agencies must establish and implement under Executive Order 12196; and DOE O 440.1, *Worker Protection Management for DOE Federal and Contractor Employees*. DOE provides implementation guidance in DOE O 440.1, including the requirements and guidelines for DOE employees.

DOE policy is the following:

- Provide places and conditions of employment that are as free as possible from recognized hazards that cause or are likely to cause illness or physical harm
- Consider 29 CFR 1960 (OSHA Standards for Federal Agencies) requirements to be the minimum standards for DOE employees
- Establish programs in safety and health training for all levels of Federal employees
- Assure that employees and employee representatives shall have the opportunity to participate in the Federal Employee Occupational Safety and Health Program

Workplace Accidents. DOE O 451.1, *National Environmental Policy Act Compliance Program*; DOE Order 5480.23, *Nuclear Safety Analysis Reports*; and DOE O 430.1, *Life-Cycle Asset Management* provide the basis for reviewing all planned and existing constructions and operations for the potential for accidents and assessing the associated human health and environmental consequences should an accident occur. The results of these reviews are used as the basis for determining the need for controls or other mitigative actions to eliminate or greatly reduce the potential for, and consequences of, an accident. These reviews are required before authorization of construction or start of operation. These reviews identify hazards and analyze normal, abnormal, and accident conditions. This analysis considers natural and manmade external events including fires, floods, tornadoes, earthquakes, other severe weather events, human errors, and explosions. The sites associated with the long-term storage and disposition proposal have complied with applicable DOE Orders.

In accordance with DOE O 151.1, *Comprehensive Emergency Management System*, emergency response planning and training are provided to mitigate the consequences of potential accidents. Additionally, should an accident occur, the incident would be reported in accordance with DOE O 232.1, *Occurrence Reporting and Processing of Operations Information*. The reports would also include appropriate corrective actions and follow-up.

Worker Health. DOE's contractor operations at each site expose workers to hazardous constituents. DOE Orders require that site operations have programs for protecting workers. DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, and DOE O 440.1, *Worker Protection Management for DOE Federal and Contractor Employees*, establish procedures for protecting workers against radiological and hazardous materials, respectively. DOE O 232.1, *Occurrence Reporting and Processing of Operations Information*, provides for reporting and guides appropriate corrective actions and follow-up should an exposure occur.

Consequences of the Weapons-Usable Fissile Materials Storage and Disposition Proposal on Candidate Site Workplace Safety and Accidents. Constructing and operating storage and disposition alternatives at potential candidate sites would result in site workers' increased exposure to industrial-type work hazards and accidents. In addition, the workers' level of risk in new construction increases in relation to the amount of changes required for such activities. Although constructing such facilities could result in injuries or fatalities, it is projected that the proposal for long-term storage and disposition will not cause any serious injuries or fatalities. All such incidences would be under the auspices of OSHA laws and regulations. Before implementing a long-term storage or disposition proposal at any site, however, the site's ES&H staff would be notified that a new process or facility is being planned, or that an existing process is being considered for change or modification to allow the impact of the anticipated change on the work environment to be evaluated.

Appropriate measures would be implemented to minimize work hazards and accidents based on this early evaluation. Once operational, as part of the Occupational Safety and Health Program at each site, ongoing surveillance of the new or modified processes or activities would be performed to identify potential health hazards. If potential health hazards are identified, a hazard evaluation would be conducted to determine the extent of the hazard and if required, the recommended control measures. Where feasible, engineering controls would be used to protect worker's health and safety. Appropriate administrative controls and personal protective equipment would supplement engineering controls.

Table J–1. Federal Environmental Statutes, Regulations, and Orders

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Air Resources	CAA, as amended	42 USC 7401 et seq.	EPA	Requires sources to meet standards and obtain permits to satisfy: National Ambient Air Quality Standards, State Implementation Plans, Standards of Performance for New Stationary Sources, NESHAP, and PSD.
	National Ambient Air Quality Standards/State Implementation Plans	42 USC 7409 et seq.	EPA	Requires compliance with primary and secondary ambient air quality standards governing SO_2, NO_2, CO, O_3, Pb, and PM_{10} and emission limits/reduction measures as designated in each state's State Implementation Plan.
	Standards of Performance for New Stationary Sources	42 USC 7411	EPA	Establishes control/emission standards and recordkeeping requirements for new or modified sources specifically addressed by a standard.
	NESHAPs	42 USC 7412	EPA	Requires sources to comply with emission levels of carcinogenic or mutagenic pollutants; may require a preconstruction approval, depending on the process being considered and the level of emissions that will result from the new or modified source.
	PSD	42 USC 7470 et seq.	EPA	Applies to areas that are in compliance with National Ambient Air Quality Standards. Requires comprehensive preconstruction review and the application of Best Available Control Technology to major stationary sources (emissions of 100 t/yr) and major modifications; requires a preconstruction review of air quality impacts and the issuance of a construction permit from the responsible state agency setting forth emission limitations to protect the PSD increment.
	Noise Control Act of 1972	42 USC 4901 et seq.	EPA	Requires facilities to maintain noise levels that do not jeopardize the health and safety of the public.
Water Resources	CWA	33 USC 1251 et seq.	EPA	Requires EPA or State-issued permits and compliance with provisions of permits regarding discharge of effluents to surface waters.
	NPDES (section 402 of CWA)	33 USC 1342	EPA	Requires permit to discharge effluents (pollutants) to surface waters and stormwaters; permit modifications are required if discharge effluents are altered.
	Dredged or Fill Material - (section 404 of CWA/ *Rivers and Harbors Appropriations Act* of 1899	33 USC 1344 33 USC 401 et seq.	U.S. Army Corps of Engineers	Requires permits to authorize the discharge of dredged or fill material into navigable waters or wetlands and to authorize certain structures or work in or affecting navigable waters.

Table J–1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Water Resources (continued)	*Wild and Scenic Rivers Act*	16 USC 1271 et seq.	United States Fish and Wildlife Service (USFWS), Bureau of Land Management, Forest Service, National Park Service	Consultation required before construction of any new Federal project associated with a river designated as wild and scenic or under study in order to minimize and mitigate any adverse effects on the physical and biological properties of the river.
	SDWA	42 USC 300f et seq.	EPA	Requires permits for construction/operation of underground injection wells and subsequent discharging of effluents to ground aquifers.
	Executive Order 11988: Floodplain Management	3 CFR, 1977 Comp., p. 117	Water Resources Council, Federal Emergency Management Agency, Council on Environmental Quality	Requires consultation if project impacts a floodplain.
	Executive Order 11990: Protection of Wetlands	3 CFR, 1977 Comp., p. 121	U.S. Army Corps of Engineers/USFWS	Requires Federal agencies to avoid the long- and short-term adverse impacts associated with the destruction or modification of wetlands.
	Compliance with Floodplain/Wetlands Environmental Review Requirements	10 CFR 1022	DOE	Requires DOE to comply with all applicable floodplain/wetlands environmental review requirements.
Hazardous Wastes and Soil Resources	RCRA /Hazardous and Solid Waste Amendments of 1984	42 USC 6901 et seq./PL 98-616	EPA	Requires notification and permits for operations involving hazardous waste treatment, storage, or disposal facilities; changes to site hazardous waste operations could require amendments to RCRA hazardous waste permits involving public hearings.
	CERCLA of 1980/SARA of 1986	42 USC 9601 et seq./PL 99-499	EPA	Requires cleanup and notification if there is a release or threatened release of a hazardous substance; requires DOE to enter into Interagency Agreements with EPA and State to control the cleanup of each DOE site on the NPL.
	Federal Land Policy and Management Act	43 USC 1701	Federal and State land-planning agencies	Requires Federal and/or State land-planning agencies to retain Federal ownership of public lands unless it is determined that disposal as such parcel will serve the national interest.

Table J–1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Hazardous Wastes and Soil Resources (continued)	NWPA of 1982	42 USC Section 10101-10270	Federal Agencies	Establishes a schedule for the siting, construction, and operation of repositories that will provide a reasonable assurance that the public and the environment will be protected from the hazards posed by disposal of high-level radioactive waste and SNF; establishes the Federal responsibility, and a definite Federal policy for the disposal of HLW and SNF; defines the relationship between the Federal and State government with respect to the disposal of HLW and SNF; and establishes a Nuclear Waste Fund.
	Community Environmental Response Facilitation Act	PL 102-426	EPA	Amends CERCLA (40 CFR 300) to establish a process for identifying, prior to the termination of Federal activities, property that does not contain contamination. Requires prompt identification of parcels that will not require remediation to facilitate the transfer of such property for economic redevelopment purposes.
	Farmland Protection Policy Act of 1981	7 USC 4201 et seq.	Soil Conservation Service	DOE shall avoid any adverse effects to prime and unique farmlands.
	Federal Facility Compliance Act of 1992	42 USC 6961	States	Waivers of sovereign immunity for Federal facilities under RCRA and requires DOE to develop plans and enter into agreements with states as to specific management actions for specific mixed waste streams.
Biotic Resources	*Fish and Wildlife Coordination Act*	16 USC 661 et seq.	USFWS	Requires consultation on the possible effects on wildlife if there is construction, modification, or control of bodies of water in excess of 10 acres in surface area.
	Bald and Golden Eagle Protection Act	16 USC 668 et seq.	USFWS	Consultations should be conducted to determine if any protected birds are found to inhabit the area. If so, DOE must obtain a permit prior to moving any nests due to construction or operation of storage or disposition facilities.
	Migratory Bird Treaty Act	16 USC 703 et seq.	USFWS	Requires consultation to determine if there are any impacts on migrating bird populations due to construction or operation of storage or disposition facilities. If so, DOE will develop mitigation measures to avoid adverse effects.
	Anadromous Fish Conservation Act	16 USC 757	USFWS	Requires consultation to determine if there are any impacts on anadromous fish that spawn in fresh water or estuaries and migrate to ocean waters and on anadromous fishery resources that are subject to deplete from water resource development.
	Wilderness Act of 1964	16 USC 1131 et seq.	DOC and DOI	DOE shall consult with the Department of Commerce and the Department of Interior and minimize impact.
	Wild Free-Roaming Horses and Burros Act of 1971	16 USC 1331 et seq.	DOI	DOE shall consult with the Department of Interior and minimize impact.

Table J–1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Biotic Resources (continued)	*Endangered Species Act* of 1973	16 USC 1531 et seq.	USFWS/National Marine Fisheries Service	Requires consultation to identify endangered or threatened species and their habitats, assess DOE impacts thereon, obtain necessary biological opinions and, if necessary, develop mitigation measures to reduce or eliminate adverse effects of construction or operation.
Cultural Resources	*National Historic Preservation Act* of 1966, as amended	16 USC 470 et seq.	President's Advisory Council on Historic Preservation	DOE shall consult with the State Historic Preservation Office prior to construction to ensure that no historical properties will be affected.
	Archaeological and Historical Preservation Act of 1974	16 USC 469 et seq.	DOI	DOE shall obtain authorization for any disturbance of archaeological resources.
	Archaeological Resources Protection Act of 1979	16 USC 470aa et seq.	DOI	DOE shall obtain authorization for any excavation or removal of archaeological resources.
	American Indian Religious Freedom Act of 1978	42 USC 1996	DOI	DOE shall consult with local Native American Indian tribes prior to construction to ensure that their religious customs, traditions, and freedoms are preserved.
	Native American Graves Protection and Repatriation Act of 1990	25 USC 3001	DOI	DOE shall consult with local Native American Indian tribes prior to construction to guarantee that no Native American graves are disturbed.
	Executive Order 11593: Protection and Enhancement of the Cultural Environment	3 CFR 154, 1971-1975 Comp., p. 559	DOI	DOE shall aid in the preservation of historic and archaeological data that may be lost during construction activities.
Worker Safety and Health	*Occupational Safety and Health Act*	5 USC 5108	OSHA	Agencies shall comply with all applicable worker safety and health legislation (including guidelines of 29 CFR 1960) and prepare, or have available, Material Safety Data Sheets.
	OSHA Guidelines	29 USC 660	OSHA	Agencies shall comply with all applicable worker safety and health legislation (including guidelines of 29 CFR 1960) and prepare, or have available, Material Safety Data Sheets.
	Hazard Communication Standard	29 CFR 1910.1200	OSHA	DOE shall ensure that workers are informed of, and trained to handle, all chemical hazards in the DOE workplace.
Other	*Atomic Energy Act* of 1954	42 USC 2011	DOE	DOE shall follow its own standards and procedures to ensure the safe operation of its facilities.
	NEPA	42 USC 4321 et seq.	CEQ	DOE shall comply with NEPA implementing procedures in accordance with 10 CFR 1021.
	Department of Energy NEPA Implementing Regulations	DOE 10 CFR Parts 1-199 (applicable sections), 820, 830, 835	DOE	DOE shall follow its own implementing regulations to ensure quality assurance, NRC agreements, and health and safety procedures.

Table J–1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Other (continued)	TSCA	15 USC 2601 et seq.	EPA	DOE shall comply with inventory reporting requirements and chemical control provisions of TSCA to protect the public from the risks of exposure to chemicals; TSCA imposes strict limitations on use and disposal of PCB-contaminated equipment.
	Hazardous Materials Transportation Act	49 USC 1801 et seq.	DOT	DOE shall comply with the requirements governing hazardous materials and waste transportation.
	Hazardous Materials Transportation Uniform Safety Act of 1990	49 USC 1801	DOT	Restricts shippers of highway route-controlled quantities of radioactive materials to use only permitted carriers.
	Emergency Planning and Community Right-To-Know Act of 1986	42 USC 11001 et seq.	EPA	Requires the development of emergency response plans and reporting requirements for chemical spills and other emergency release, and imposes right-to-know reporting requirements covering storage and use of chemicals that are reported in toxic chemical release forms.
	Executive Order 12088: Federal Compliance with Pollution Control Standards	3 CFR, 1978 Comp., p. 243	Office of Management and Budget (OMB)	Requires Federal agency landlords to submit to OMB an annual plan for the control of environmental pollution and to consult with EPA and State agencies regarding the best techniques and methods.
	Executive Order 11514: Protection and Enhancement of Environmental Quality	3 CFR, 1966-1970 Comp., p. 902	CEQ	Requires Federal agencies to demonstrate leadership in achieving the environmental quality goals of NEPA; provides for DOE consultation with appropriate Federal, State, and local agencies in carrying out their activities as they affect the environment.
	Pollution Prevention Act of 1990	42 USC 11001-11050	EPA	Establishes a national policy that pollution should be reduced at the source and requires a toxic chemical source reduction and recycling report for an owner or operator of a facility required to file an annual toxic chemical release form under section 313 of SARA.
	Executive Order 11988: Floodplain Management	3 CFR 1977 Comp., p. 117	Var. Agencies and EPA	Directs Federal agencies to establish procedures to ensure that the potential effects of flood hazards and floodplain management are considered for any action undertaken in a floodplain and that floodplain impacts be avoided to the extent practicable.
	Executive Order 12114: Environment Affects Abroad Major Federal Actions	January 4, 1979	DOE	Requires officials of Federal agencies having ultimate responsibility for authorizing and approving actions encompassed by this Order to be informed of pertinent environmental considerations and to take such considerations into account, with other pertinent considerations of national policy in making decisions regarding such actions. While based on independent authority, this Order furthers the purpose of NEPA.

Table J-1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Other (continued)	Executive Order 12372: Intergovernmental review of federal programs	July 14, 1982	DOE	Requires Federal agencies to provide opportunities for consultation by elected officials of those State and local governments that would provide the non-Federal funds for or that would be directly affected by proposed Federal financial assistance or direct Federal development.
	Executive Order 12843: Procurement Requirements and Policies for Federal Agencies for Ozone-Depleting Substances	April 21, 1993	EPA	Requires Federal agencies to minimize procurement of ozone-depleting substances and conform their practices to comply with Title VI of CAA Amendments reference stratospheric ozone protection and to recognize the increasingly limited availability of Class I substances until final phaseout.
	Executive Order 12856: Federal Compliance with Right-To-Know Laws and Pollution Prevention Requirements	August 3, 1993	EPA	Requires Federal agencies to achieve 50 percent reduction of agency's total releases of toxic chemicals to the environment and offsite transfers, to prepare a written facility pollution prevention plan not later than 1995, and to publicly report toxic chemicals entering any waste stream from Federal facilities, including any releases to the environment, and to improve local emergency planning, response and accident notification.
	Executive Order 12873: Federal Acquisition, Recycling, and Waste Prevention	October 20, 1993	EPA	Requires Federal agencies to develop affirmative procurement policies and establishes a shared responsibility between the system program manager and the recycling community to effect use of recycled items for procurement.
	Executive Order 12898: Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	February 11, 1994	EPA	Requires Federal agencies to identify and address as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations.
	Executive Order 12580: Superfund Implementation	January 23, 1987	Executive Depts. and DOE	Delegates to the heads of executive departments and agencies the responsibility for undertaking remedial actions for releases, or threatened releases that are not on the NPL and removal actions other than emergencies where the release is from any facility under the jurisdiction or control of executive departments and agencies
	Executive Order 12856: Right to Know Laws and Pollution Prevention Requirements	August 3, 1993	DOE	Directs all Federal agencies to reduce and report toxic chemicals entering any wastestream; improve emergency planning, response, and accident notification; and encourage clean technologies and testing of innovative prevention technologies. The executive order also provides the Federal agencies are persons for purposes of the *Emergency Planning and Community Right-to-Know Act* (SARA Title iii), which obliges agencies to meet the requirements of the Act.

Table J–1. Federal Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Statute/Regulation/Order	Citation	Responsible Agency	PEIS-Level Potential Applicability: Permits, Approvals, Consultations, and Notifications
Other (continued)	Executive Order 10480: Further Providing for the Administration of the Defense Mobilization Program	August 1953	Federal Emergency Management Agency	Delegates to the Director, Federal Emergency Management Agency with authority to redelegate, the priorities and allocation functions conferred on the President by Title I of the *Defense Production Act* of 1950, as amended.
	Executive Order 12148: Federal Emergency Management	July 20, 1979	Federal Emergency Management Agency	Transferred functions and responsibilities associated with Federal emergency management to the Director, Federal Emergency Management Agency. The Order assigns the Director, Federal Emergency Management Agency, the responsibility to establish Federal policies for and to coordinate all civil defense and civil emergency planning, management, mitigation, and assistance functions of Executive Agencies.
	Executive Order 12472: Assignment of National Security and Emergency Preparedness Telecommunications Function	April 3, 1984	DOE	Establishes the National Communication System. The National Communication System consists of the telecommunications assets of the entities represented on the National Communication System Committee of Principals and an administrative structure consisting of the Executive Agent, the National Communication System Committee of Principals, and the Manager.
	Executive Order 12656: Assignment of Emergency Preparedness Responsibilities	November 1988	DOE	This order assigns emergency preparedness responsibilities to Federal departments and agencies.
	Low-Level Radioactive Waste Policy Act	42 USC 2021b-2021d	DOE	DOE shall dispose of LLW per compacts of the states in which it operates.

Table J–2. State Environmental Statutes, Regulations, and Orders

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
Hanford, Washington State				
Air Resources	*Washington Clean Air Act*	Revised Code of Washington (RCW) Chapter 70.94	WA Department of Ecology	Required to register and obtain permits for new resources.
	Noise Control Act of 1974	RCW, Ch 70.107	WA Department of Ecology	Required to comply with anti-noise measures.
Water Resources	*Coastal Waters Protection Act* of 1971	RCW, Ch. 90.48	WA Department of Ecology	Water pollution control requirements; applies to all waters of the State.
	Chemical Contaminants and Water Quality	RCW, Ch. 70.142	WA Department of Ecology	Water pollution control requirements.
	Water Rights of the United States	RCW, Ch. 90.40	NA	Federal eminent domain.
Hazardous Wastes and Soil Resources	*Hazardous Waste Management Act*	RCW, Ch. 70.105	WA Department of Ecology	Permits required for various activities involving hazardous waste.
	Nuclear Energy and Radiation	RCW, Ch. 70.98	WA Department of Ecology	Licensing and permitting of radiation sources.
	Radioactive Waste Storage and Transport Act of 1980	RCW, Ch. 70.99	WA Department of Ecology	Establishes various requirements for handling and storage of rad waste.
	Radioactive Waste Act	RCW, Ch. 43.200	WA Department of Ecology	Establishes various requirements for handling and storage of rad waste.
Biotic Resources	Various Acts Concerning Fish and Game	RCW, Ch. 77	WA Department of Fish and Wildlife	May require consultation with responsible agency.
Other	*State Environmental Policy Act*	RCW, Ch. 43.21C	WA Department of Ecology	Required to prepare "detailed statement" on environmental impacts of proposed actions.
	Underground Tanks	WAC, Ch. 173-360	WA Department of Ecology	Required to follow regulations if underground storage tanks involved in project.
Cultural resources	Archaeology and Historic Preservation	RCW, Ch. 43.51A	WA Office of Archaeology and Historic Preservation	Required to follow rules designated to protect state cultural resources.
INEL, Idaho				
Air Resources	*Idaho Environmental Protection and Health Act*	ID Code, Title 39, Chapter 101	ID Department of Health and Welfare	Permit required prior to construction or modification of an air contaminant source.
	Idaho Department of Health and Welfare Rules	ID Code, Title 39, Chapter 1	ID Department of Health and Welfare	Permit required prior to construction or modification of an air contaminant source.
Water Resources	Idaho Wastewater-Land Application Permit Regulations	ID Rules/Regs., Title 1, Chapter 17	ID Department of Health and Welfare	Permit required prior to construction or modification of a water discharge source.
	Idaho Water Pollution Control Act	ID Code, Title 39, Chapter 36	ID Department of Health and Welfare	Permit required prior to construction or modification of a water discharge source.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
	Idaho Water Quality Standards	ID Rules/Regs., Title 1, Chapter 2	ID Department of Water Resources, Resource Administration Division	Permit required prior to the construction or operation of a wastewater injection well.
	Idaho Stream Channel Protection Act	ID Code, Title 42, Chapter 38	ID Department of Water Resources	Permit required prior to dredge or fill of any stream.
	Idaho Lake Protection Act	ID Code, Section 58-142 et seq.	ID Department of Lands	Permit required prior to dredge or fill of any lake.
Hazardous Wastes and Soil Resources	*Idaho Hazardous Waste Management Act*	ID Code, Title 39, Chapter 44	ID Department of Health and Welfare	Permit required prior to construction or modification of a hazardous waste disposal facility.
	Idaho Hazardous Waste Management Regulations	ID Rules/Regs., Title 1, Chapter 5	ID Department of Health and Welfare	Permit required prior to construction or modification of a hazardous waste disposal facility.
Biotic Resources	Various Acts Regarding Fish and Game	ID Code, Title 36	ID Department of Fish and Game	May require consultation with responsible agency.
Cultural Resources	*Idaho Historic Preservation Act*	ID Code, Title 67, Chapter 46	ID Historic Preservation Commission	Consult with responsible local governing body.
Los Alamos National Laboratory, New Mexico				
Air Resources	*New Mexico Air Quality Control Act*	NM Stat., Title 74, Article 2	NM Health and Environmental Department	Permit required prior to the construction or modification of an air contaminant source.
	New Mexico Air Quality Standards and Regulations	NM Air Quality Control Regs., 100	NM Health and Environmental Department	Permit required prior to the construction or modification of an air contaminant source.
Water Resources	*New Mexico Water Quality Act*	NM Stat., Title 74, Article 6	NM Water Quality Control Com.	Permit required prior to the construction or modification of a water discharge source.
	New Mexico Water Quality Regulations	NM Water Regulations	NM Water Quality Control Com.	Permit required prior to the construction or modification of a water discharge source.
Hazardous Wastes and Soil Resources	*New Mexico Solid Waste Act*	NM Stat., Chap. 74, Article 8	NM Health and Environmental Dept.	Permit required prior to the construction or modification of a solid waste disposal facility.
	New Mexico Solid Waste Management Regulations	NM Solid Waste Mgmt. Regs.	NM Environmental Improvement Div.	Permit required prior to the construction or modification of a solid waste disposal facility.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
	New Mexico Hazardous Waste Management Regulations	NM Hazardous Waste Mgmt. Regs.	NM Environmental Improvement Div.	Permit required prior to the construction or modification of a hazardous waste disposal facility.
	New Mexico Underground Storage Tank Regulations	NM Underground Storage Tank Regulations	NM Health and Environmental Dept.	Permit required to comply with tank requirements prior to the construction or modification of an underground storage tank.
Biotic Resources	*New Mexico Wildlife Conservation Act*	NM State Act 1978, Sections 17–2–37 through 17–2–46	NM Department of Game and Fish	Permit and coordination required if a project may disturb habitat or otherwise affect threatened or endangered species.
	New Mexico Endangered Plant Species Act	NM State Act 1978, Sections 75–6–1	NM State Forestry Department	Coordination with the department required.
Cultural Resources	*New Mexico Cultural Properties Act*	NM State Act 1978, Sections 18–6–23	NM State Historic Preservation Office	Established State Historic Preservation Office and requirements to prepare an archaeological and historic survey and consult with the State Historic Preservation Office.
Worker Safety and Health	No state-level legislation identified	NA	NA	NA
NTS, Nevada				
Air Resources	Nevada Air Pollution Control Law	NV Statutes, Title 40	NV State Environmental Commission	Permit required prior to construction or modification of an air contaminant source.
	Nevada Air Quality Regulations	NV Admin. Code, Chapter 445	NV State Environmental Commission	Permit required prior to construction or modification of an air contaminant source.
Water Resources	Nevada Water Pollution Control Law	NV Statutes, Title 40, Chapter 445	NV Department of Environmental Protection	Permit required prior to construction or modification of a water discharge source.
	Nevada Water Pollution Control Regulations	NV Admin. Code, Chapter 445	NV Department of Environmental Protection	Permit required prior to construction or modification of a water discharge source.
Hazardous Wastes and Soil Resources	Nevada Underground Storage Tank Rules	NV Admin. Code, Chapter 459	NV Department of Environmental Protection	Permit required prior to construction or modification of an underground storage tank.
	Nevada Solid Waste Disposal Law	NV Statutes, Title 40, Chapter 444	NV Department of Environmental Protection	Permit required prior to construction or modification of a solid waste disposal facility.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
	Nevada Solid Waste Disposal Regulations	NV Admin. Code, Chapter 44	NV Department of Environmental Protection	Permit required prior to construction or modification of a solid waste disposal facility; permit for septage hauling may be required.
	Nevada Hazardous Waste Disposal Law	NV Statutes, Title 40, Chapter 459	NV Department of Environmental Protection	Permit required prior to construction or modification of a hazardous waste disposal facility.
	Nevada Hazardous Waste Facility Regulations	NV Admin. Code, Chapter 444	NV Department of Environmental Protection	Permit required prior to construction or modification of a hazardous waste disposal facility.
Biotic Resources	*Nevada Non-Game Species Act*	NV Admin. Code, Title 45, Chapter 503	NV Department of Wildlife	Consult with NV Department of Wildlife and minimize impact.
Cultural Resources	Historic Preservation and Archaeology Regulations	NV Statutes, Title 26, Chapter 381-383	NV Advisory Board for Historic Preservation and Archaeology	Permit required prior to the investigation, exploration, or excavation of a historic or prehistoric site.
ORR, Tennessee				
Air Resources	Tennessee Air Pollution Control Regulations	TN Rules, Division of Air Pollution	TN Air Pollution Control Board	Permit required to construct, modify, or operate an air contaminant source; sets fugitive dust requirements.
Water Resources	*Tennessee Water Quality Control Act*	TN Code, Title 69, Chapter 3	TN Water Quality Control Board	Authority to issue new or modify existing NPDES permits required for a water discharge source.
Hazardous Wastes and Soil Resources	Tennessee Underground Storage Tank Program Regulations	TN Rules, Chapter 1200-1-15	TN Division of UST Programs	Permit required prior to construction or modification of an underground storage tank.
	Tennessee Hazardous Waste Management Act	TN Code, Title 68, Chapter 46	TN Division of Solid Waste Management	Permit required to construct, modify, or operate a hazardous waste treatment, storage, or disposal facility.
	Tennessee Solid Waste Processing and Disposal Regulations	TN Rules, Chapter 1200-1-7	TN Division of Solid Waste Management	Permit required to construct or operate a solid waste processing or disposal facility.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
Biotic Resources	Tennessee State Executive Order on Wetlands	TN State Executive Order	TN Division of Water Quality Control	Consultation with responsible agency.
	Tennessee Threatened Wildlife Species Conservation Act of 1974	TN Code, Title 70, Chapter 8	TN Wildlife Resources Agency	Consultation with responsible agency.
	Tennessee Rare Plant Protection and Conservation Act of 1985	TN Code, Title 70, Chapter 8-301 et seq.	TN Wildlife Resources Agency	Consultation with responsible agency.
	Tennessee Water Quality Control Act	TN Code, Title 69, Chapter 3	TN Division of Water Quality Control	Permit required prior to alteration of a wetland.
Cultural Resources	Tennessee Desecration of Venerated Objects	TN Code, Title 39, Chapter 17-311	TN Historical Commission	Forbids a person to offend or intentionally desecrate venerated objects including a place of worship or burial.
Pantex, Texas				
Air Resources	Texas Air Pollution Control Regulations	TX Admin. Code, Title 30, Chapter 101-125, 305	Texas Natural Resource Conservation Commission (TNRCC) (effective 9/1/93)	Permit required prior to construction or modification of an air contaminant source.
Water Resources	Texas Water Quality Standards	TX Admin. Code, Title 30, Chapter 305, 308-325	TNRCC (effective 9/1/93)	A permit may be required prior to any modification of waters of the State including stream alteration for the construction of intakes, discharges, bridges, submarine utility crossings, etc. discharge source.
	Texas Consolidated Permit Rules	TX Admin. Code, Title 30	TNRCC (effective 9/1/93)	Permit required prior to construction or modification of a water discharge source.
	Texas Water Quality Acts	TX Code, Title 30, Chapter 290	TNRCC (effective 9/1/93)	Permit required prior to construction or modification of a water discharge source affecting a public water supply.
Hazardous Wastes and Soil Resources	Texas Underground Storage Tanks Rules	TX Admin. Code, Title 30, Chapter 334	TNRCC (effective 9/1/93)	Permit required prior to construction or modification of an underground storage tank.
	Texas Solid Waste Management Regulations	TX Admin. Code, Title 30, Chapter 305, 335	TNRCC (effective 9/1/93)	Permit required prior to construction or modification of a solid waste disposal facility.
	Texas Solid Waste Disposal Act	TX Statutes, Article 4477-7	TNRCC (effective 9/1/93)	Permit required prior to construction or modification of a solid waste disposal facility.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
Biotic Resources	Texas Parks and Wildlife Regulations	TX Parks and Wildlife Code, Chapters 67, 68, & 88	TX Parks and Wildlife Department	Permit required by anyone who possesses, takes, or transports endangered, threatened, or protected plants or animals.
Cultural Resources	Antiquities Code of Texas	TX Statutes, Volume 17, Article 6145	TX State Historical Survey Committee	Permit required for the examination or excavation of sites and the collection or removal of objects of antiquity.
	Tennessee Abuse of Corpse	TN Code, Title 39, Chapter 17-312	TX Historical Commission	Forbids a person from disinterring a corpse that has been buried or otherwise interred.
	Native American Indian Cemetery Removal and Reburial	TN Comp. Rules and Regulations, Chapter 400-9-1	TX Historical Commission	Requires notification if Native American Indian remains are uncovered.
	Tennessee Protective Easements	TN Code, Title 11, Chapter 15-101	TX State Government	Grants power to the State to restrict construction on land deemed as a "protective" easement.
RFETS, Colorado				
Air Resources	*Colorado Air Quality Control Act*	Colorado Revised Statutes (CRS) Title 25, Article 7	CO Air Quality Control Comm.	Required to follow emission control regulations.
Water Resources	*Colorado Water Quality Control Act*	CRS, Title 25, Article 8	CO Water Quality Control Comm.	Required to follow regulations governing water quality.
Hazardous wastes and soil resources	Hazardous waste management, storage, and disposal	CRS, Title 25, Article 15, Part 3	CO Department of Health	Permits required for various activities involving hazardous waste.
Biotic resources	*Nongame, Endangered, and Threatened Species Act*	CRS, Title 33, Article 2	CO Division of Wildlife; Wildlife Commission	May require consultation with responsible agency.
Other	Underground Storage Tanks	CRS, Title 8, Article 20, Part 5; Title 25, Article 18	CO State Inspector of Oils	Required to follow regulations concerning underground storage tanks.
Cultural Resources	State history, archives, and emblems	CRS, Title 24, Article 80	CO Historical Society	Required to follow laws to protect state historical/archaeological resources.

Table J–2. State Environmental Statutes, Regulations, and Orders—Continued

Resource Category	Legislation	Citation	Responsible Agency	Potential Applicability/Permits
SRS, South Carolina				
Air Resources	*South Carolina Pollution Control Act*/South Carolina Air Pollution Control Regulations and Standards	SC Code, Title 48, Chapter 1	SC Department of Health and Environmental Control	Permit required prior to construction or modification of an air contaminant source.
	Augusta-Aiken Air Quality Control Region	40 CFR 81.114	SC and GA Department of Health and Environmental Control	Requires SRS and surrounding communities in the two-State region to attain NAAQS.
	South Carolina Atomic Energy & Radiation Control Act	SC Code, Title 13, Chapter 7	SC Department of Health and Environmental Control	Establishes standards for radioactive air emissions.
Water Resources	*South Carolina Pollution Control Act*	SC Code, Title 48, Chapter 1	SC Department of Health and Environmental Control	Permit required prior to construction or modification of a water discharge source.
	South Carolina Water Quality Standards	SC Code, Title 61, Chapter 68	SC Department of Health and Environmental Control	Permit required prior to construction or modification of a water discharge source.
	South Carolina Safe Drinking Water Act	SC Code, Title 44, Chapter 55	SC Department of Health and Environmental Control	Establishes drinking water standards.
Hazardous Wastes and Soil Resources	*South Carolina Underground Storage Tanks Act*	SC Code, Title 44, Chapter 2	SC Department of Health and Environmental Control	Permit required prior to construction or modification of an underground storage tank.
	South Carolina Solid Waste Regulations	SC Code, Title 61, Chapter 60	SC Department of Health and Environmental Control	Permit required to store, collect, dispose, or transport solid wastes.
	South Carolina Industrial Solid Waste Disposal Site Regulations	SC Code, Title 61, Chapter 66	SC Pollution Control Authority	Permit required for industrial solid waste disposal systems.
	South Carolina Hazardous Waste Management Act	SC Code, Title 44, Chapter 56	SC Department of Health and Environmental Control	Permit required to operate, construct, or modify a hazardous waste treatment, storage, or disposal facility.
	South Carolina Solid Waste Management Act	SC Code, Title 44, Chapter 96	SC Department of Health and Environmental Control	Establishes standards to treat, store, or dispose of solid waste.
Biotic Resources	*South Carolina Nongame and Endangered Species Conservation Act*	SC Code, Title 50, Chapter 15	SC Wildlife and Marine Resources Department	Consult with Wildlife and Marine Resources Department and minimize impact.
Cultural Resources	South Carolina Institute of Archaeology and Anthropology	SC Code, Title 60, Chapter 13-210	SC State Historic Preservation Office	Consult with State Historic Preservation Office and minimize impact.

Note: NA=not applicable.

Table J–3. Selected Department of Energy Environment, Safety, and Health Orders

DOE Order	Order Title
O 151.1	Comprehensive Emergency Management System
O 210.1	Performance Indicators and Analysis of Operations Information
O 225.1	Accident Investigations
O 231.1	Environment, Safety, and Health Reporting
O 232.1	Occurrence Reporting and Processing of Operation Information
O 360.1	Training
O 420.1	Facility Safety
O 425.1	Startup and Restart of Nuclear Facilities
O 430.1	Life-Cycle Assets Management
O 440.1	Worker Protection Management for DOE Federal and Contractor Employees
O 440.2	Aviation
N 441.1	Radiological Protection for DOE Activities
O 451.1	*National Environmental Policy Act* Compliance Program
O 452.1	Nuclear Explosive and Weapons Surety
O 452.2	Safety of Nuclear Explosive Operations
O 460.1	Packaging and Transportation Safety
O 460.2	Departmental Materials Transportation and Packaging Management
O 470.1	Safeguards and Security Program
O 471.2	Information Security Program
O 472.1	Personnel Security Activities
1300.2A	Department of Energy Technical Standards Program
1360.2B	Unclassified Computer Security Program
3790.1B	Federal Employee Occupational Safety and Health Program
4330.4B	Maintenance Management Program
4700.1	Project Management System
5400.1	General Environmental Protection Program
5400.5	Radiation Protection of the Public and the Environment
5480.4	Environmental Protection, Safety, and Health Protection Standards
5480.19	Conduct of Operations Requirements for DOE Facilities
5480.20A	Personnel Selection Qualifications, Training, and Staffing Requirements at DOE Reactor and Nonreactor Nuclear Facilities
5480.21	Unreviewed Safety Questions
5480.22	Technical Safety Requirements
5480.23	Nuclear Safety Analysis Reports
5482.1B	Environment, Safety, and Health Appraisal Program
5484.1	Environmental Protection, Safety, and Health Protection Information Reporting Requirements
5530.1A	Accident Response Group
5530.3	Radiological Assistance Program
5530.4	Aerial Measuring System
5530.5	Federal Radiological Monitoring and Assessment Center
5630.12A	Safeguards and Security Inspection and Assessment Program
5630.13	Master Safeguards and Security Agreements
5632.1C	Protection and Control of Safeguards and Security Interests
5633.3B	Control and Accountability of Nuclear Materials
5700.6C	Quality Assurance
5820.2A	Radioactive Waste Management

Table J–4. Applicable Nuclear Regulatory Commission Guidelines

Guide Number	Title	Latest Rev. Date
3.3	Quality Assurance Program Requirements for Fuel Reprocessing Plants and for Plutonium Processing and Fuel Fabrication Plants	3/74
3.7	Monitoring of Combustible Gases and Vapors in Plutonium Processing and Fuel Fabrication Plants	3/73
3.10	Liquid Waste Treatment System Design Guide for Plutonium Processing and Fuel Fabrication Plants	6/73
3.12	General Design Guide for Ventilation Systems of Plutonium Processing and Fuel Fabrication Plants	8/73
3.14	Seismic Design Classification for Plutonium Processing and Fuel Fabrication Plants	10/73
3.16	General Fire Protection Guide for Plutonium Processing and Fuel Fabrication Plants	1/74
3.21	Quality Assurance Requirements for Protective Coatings Applied to Fuel Reprocessing and to Plutonium Processing and Fuel Fabrication Plants	3/74
3.28	Welder Qualifications for Welding in Areas of Limited Accessibility in Fuel Reprocessing and in Plutonium Processing and Fuel Fabrication Plants	5/75
3.29	Preheat and Interpass Temperature Control for the Welding of Low-Alloy Steel for Use in Fuel Reprocessing Plants and in Plutonium Processing and Fuel Fabrication Plants	5/75
3.35	Assumptions Used for Evaluating the Potential Radiological Consequences of Accidental Nuclear Criticality in a Plutonium Processing and Fuel Fabrication Plant	7/79
3.39	Standard Format and Content of License Applications for Plutonium Processing and Fuel Fabrication Plants	1/76
3.40	Design Basis Floods for Fuel Reprocessing Plants and for Plutonium Processing and Fuel Fabrication Plants	12/72
3.47	Nuclear Criticality Control and Safety of Homogeneous Plutonium-Uranium Fuel Mixtures Outside Reactors	7/81

Appendix K
Biological Resources

Table K–1 contains a listing of the scientific names of common, nonthreatened, and nonendangered animal and plant species found in Chapters 3 and 4. Species are grouped and listed in alphabetical order by common name.

Table K–1. Scientific Names of Nonthreatened and Nonendangered Animal and Plant Species Referred to in the Text

Common Name	Scientific Name
Mammals	
Abert's squirrel	*Sciurus aberti*
Badger	*Taxidea taxus*
Beaver	*Castor canadensis*
Bighorn sheep	*Ovis canadensis*
Black bear	*Ursus americanus*
Black-footed ferret	*Mustela nigripes*
Black-tailed jackrabbit	*Lepus californicus*
Black-tailed prairie dog	*Cynomys ludovicianus*
Bobcat	*Lynx rufus*
[Text deleted.]	
Cactus mouse	*Peromyscus eremicus*
Coyote	*Canis latrans*
Deer mouse	*Peromyscus maniculatus*
Desert cottontail	*Sylvilagus auduboni*
Eastern cottontail	*Sylvilagus floridanus*
Eastern gray squirrel	*Sciurus carolinensis*
Elk	*Cervus elaphus*
Feral hog	*Sus scrofa*
Gray fox	*Urocyon cinereoargenteus*
Great Basin kangaroo rat	*Dipodomys microps*
Great Basin pocket mouse	*Perognathus parvus*
Hispid cotton rat	*Sigmodon hispidus*
Javelina	*Pecari angulatus*
Long-tailed weasel	*Mustela frenata*
Merriam's kangaroo rat	*Dipodomys merriami*
Mexican woodrat	*Neotoma mexicana*
Mink	*Mustela vison*
Moose	*Alces alces*
Mountain cottontail	*Sylvilagus nuttalli*
Mountain lion	*Felis concolor*
Mule deer	*Odocoileus hemionus*
Opossum	*Didelphis marsupialis*
[Text deleted.]	
Porcupine	*Erethizon dorsatum*
Pronghorn	*Antilocapra americana*
Raccoon	*Procyon lotor*
Red squirrel	*Tamiasciurus hudsonicus*
Round-tailed ground squirrel	*Spermophilus tereticaudus*
Snowshoe hare	*Lepus americanus*
Thirteen-lined ground squirrel	*Spermophilus tridecemlineatus*
Townsend's ground squirrel	*Spermophilus townsendii*
White-footed mouse	*Peromyscus leucopus*
Whitetail deer	*Odocoileus virginianus*
Birds	
[Text deleted.]	
American kestrel	*Falco sparverius*
American robin	*Turdus migratorius*
Black vulture	*Coragyps atratus*
Black-throated sparrow	*Amphispiza bilineata*
Boreal chickadee	*Parus hudsonicus*
[Text deleted.]	
Canada goose	*Branta canadensis*
Carolina chickadee	*Parus carolinensis*
Common crow	*Corvus brachyrhynchos*
Common raven	*Corvus corax*
Downy woodpecker	*Picoides pubescens*
Eastern bluebird	*Sialia sialis*
Forster's tern	*Sterna forsteri*
Gambel's quail	*Callipepla gambelii*
Great blue heron	*Ardea herodias*
[Text deleted.]	
Great horned owl	*Bubo virginianus*
Greater prairie chicken	*Tympanuchus cupido*
Greater roadrunner	*Geococcyx californianus*
Horned lark	*Eremophila alpestris*
House finch	*Carduelis mexicanus*
Lesser goldfinch	*Carduelis psaltria*
Magpie	*Pica spp.*
Mourning dove	*Zenaida macroura*
Nighthawk	*Chordeiles spp.*
Northern bobwhite	*Colinus virginianus*
Northern cardinal	*Cardinalis cardinalis*
[Text deleted.]	
Northern harrier	*Circus cyaneus*
Ovenbird	*Seiurus aurocapillus*
Pelican	*Pelecanus spp.*
Pine siskin	*Carduelis pinus*
Raven	*Corvus spp.*
Red crossbill	*Loxia curvirostra*
Red-breasted nuthatch	*Sitta canadensis*
Red-tailed hawk	*Buteo jamaicensis*
Ring-billed gull	*Larus delawarensis*
Ring-necked pheasant	*Phasianus colchicus*
Rough-legged hawk	*Buteo lagopus*
Ruffed grouse	*Bonasa umbellus*
Sage grouse	*Centrocercus urophasianus*
Say's phoebe	*Sayornis saya*
Scaled quail	*Callipepla squamata*
Scrub jay	*Aphelocoma coerulescens*
Turkey vulture	*Cathartes aura*
Western meadowlark	*Sturnella neglecta*
Wild turkey	*Meleagris gallopavo*
Wood thrush	*Hylocichla mustelina*

Table K–1. Scientific Names of Nonthreatened and Nonendangered Animal and Plant Species Referred to in the Text—Continued

Common Name	Scientific Name
Worm-eating warbler	*Helmitheros vermivorus*
[Text deleted.]	
Reptiles	
Banded gecko	*Coleonyx variegatus*
[Text deleted.]	
Collared lizard	*Crotaphytus collaris*
Common bullsnake	*Pitriophis melanoleucus*
Common garter snake	*Thamnophis sirtalis*
[Text deleted.]	
Desert iguana	*Dipsosaurus dorsalis*
Eastern box turtle	*Terrapene carolina*
Eastern diamondback rattlesnake	*Crotalus adamanteus*
Eastern fence lizard	*Sceloporus undulatus*
Eastern garter snake	*Thamnophis sirtalis*
Eastern ribbon snake	*Thamnophis sauritus*
Gopher snake	*Pituophis melanoleucus*
[Text deleted.]	
Painted turtle	*Chrysemys picta*
Prairie kingsnake	*Lampropeltis calligaster*
Prairie rattlesnake	*Crotalus viridis*
Rat snake	*Elaphe obsoleta*
Ring-necked snake	*Diadophis punctatus*
Sagebrush lizard	*Sciloporus graciosus*
Short-horned lizard	*Phyrnosoma douglassi*
Side-blotched lizard	*Uta stansburiana*
Smooth green snake	*Opheodrys vernalis*
Western box turtle	*Terrapene ornata*
[Text deleted.]	
Western shovel-nosed snake	*Chionactis occipitalis*
Western skink	*Eumeces skeltonianus*
Whiptail lizard	*Cnemidophorus spp.*

Common Name	Scientific Name
Amphibians	
American toad	*Bufo americanus*
[Text deleted.]	
Chorus frog	*Pseudacris triseriata*
[Text deleted.]	
Great Plains toad	*Bufo cognatus*
[Text deleted.]	
Green frog	*Rana clamitans*
[Text deleted.]	
Pine woods treefrog	*Hyla femoralis*
Slimy salamander	*Plethodon glutinosus*
Spotted salamander	*Ambystoma maculatum*
Fish	
American shad	*Alosa sapidissima*
Banded sculpin	*Cottus carolinae*
Black crappie	*Pomoxis nigromaculatus*
Blacknose dace	*Rhinichthys atratulus*
Blueback herring	*Alosa aestivalis*
Bluegill	*Lepomis macrochirus*
Bluntnose minnow	*Pimephales notatus*
Bream	*Lepomis spp.*
Brook trout	*Salvelinus fontinalis*
Brown trout	*Salmo trutta*
Carpsucker	*Carpiodes spp.*
Central stoneroller	*Campostoma anomalum*
Channel catfish	*Ictalurus punctatus*
Chinook salmon	*Oncorhynchus tshawytscho*
Chub	*Cyprinidae*
Coho salmon	*Oncorhynchus kisutch*
Common carp	*Cyprinus carpio*
Crappie	*Pomoxis spp.*
Creek chub	*Semotilus atromaculatus*

Common Name	Scientific Name
Fathead minnow	*Pimephales promelas*
Freshwater drum	*Aplodinotus grunniens*
Golden shiner	*Notemigonus crysoleucas*
Goldfish	*Carassius auratus*
Green sunfish	*Lepomis cyanellus*
Hickory shad	*Alosa mediocris*
Kokanee salmon	*Oncorhynchus nerka*
Lake chubsucker	*Erimyzon sucetta*
Largemouth bass	*Micropterus salmoides*
Mosquitofish	*Gambusia affinis*
Mountain whitefish	*Prosopium williamsoni*
Mud sunfish	*Acantharchus pomotis*
Pickerel	*Esox spp.*
Rainbow trout	*Oncorhynchus mykiss*
Redbreast sunfish	*Lepomis auritus*
Redfin pickerel	*Esox americanus*
Redside dace	*Clinostomus elongatus*
Rock bass	*Ambloplites rupestris*
Sauger	*Stizostedion canadense*
Shorthead sculpin	*Cottus confusus*
Smallmouth bass	*Micropterus dolomieu*
Sockeye salmon	*Oncorhynchus nerka*
Speckled dace	*Rhinichthys osculus*
Steelhead trout	*Oncorhynchus mykiss*
Striped bass	*Morone saxatilis*
Sunfish	*Lepomis spp.*
Walleye	*Stizostedion vitreum*
White sturgeon	*Acipenser transmontanus*
White sucker	*Catostomus commersoni*
Plants	
American elm	*Ulmus americana*
American watercress	*Barbarea orthoceras*
Aspen	*Populus spp.*

Table K–1. Scientific Names of Nonthreatened and Nonendangered Animal and Plant Species Referred to in the Text—Continued

Common Name	Scientific Name
Bald cypress	*Taxodium distichum*
Balsam fir	*Abies balsamea*
Basswood	*Tilia americana*
Beech	*Fagus spp.*
Big sagebrush	*Artemisia tridentata*
Blackbrush	*Coleogyne ramosissima*
Blue grama	*Bouteloua gracilis*
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Broadleaf cattail	*Typha latifolia*
Buffalo-grass	*Buchloe dactyloides*
Bulrush	*Scirpus spp.*
Canada bluegrass	*Poa canbyi*
Cattail	*Typha spp.*
Cedar	*Juniperus virginiana*
Cheatgrass	*Bromus tectorum*
Cholla	*Opuntia sp.*
Cottonwood	*Populus spp.*
Creosote bush	*Larrea tridentata*
Crested wheatgrass	*Agropyron desertorum*
Desert thorn	*Lycium pallidum*
Desert thorn	*Lycium shockleyi*
Douglas fir	*Pseudotsuga menziesii*
Fir	*Abies sp.*
Giant wildrye	*Elymus condensatus*
Gray horsebrush	*Tetradymia canescens*
Gray rabbitbrush	*Chrysothamnus nauseous*
Greasewood	*Sarcobatus vermiculatus*
Green rabbitbrush	*Chrysothamnus greenei*
Hemlock	*Tsuga canadensis*
Hickory	*Carya spp.*
Hopsage	*Grayia spinosa*
Indian ricegrass	*Oryzopsis hymenoides*
Juniper	*Juniperus spp.*
Little bluestem	*Schizachyrium scoparium*
Loblolly pine	*Pinus taeda*
Longleaf pine	*Pinus palustris*
Low sagebrush	*Artemisia arbuscula*
Maple	*Acer spp.*
Needle-and-thread grass	*Stipa comata*
Oak	*Quercus spp.*
One-seed juniper	*Juniperus monosperma*
Paper birch	*Betula papyrifera*
Peachleaf willow	*Salix amygdaloides*
Pine	*Pinus spp.*
Pinyon pine	*Pinus edulis*
Pitch pine	*Pinus rigida*
Plains cottonwood	*Populus sargentii*
Ponderosa pine	*Pinus ponderosa*
[Text deleted.]	
Poplar	*Populus spp.*
Poverty-weed	*Monolepis nuttaliana*
Prickly pear cactus	*Opuntia spp.*
Rabbitbrush	*Chrysothamnus spp.*
Red brome	*Bromus rubens*
Red oak	*Quercus rubra*
Red spruce	*Picea rubens*
[Text deleted.]	
Rush	*Juncus spp.*
Russian thisle	*Salsola kali*
Sagebrush	*Artemisia spp.*
Saltbush	*Atriplex spp.*
Sandbar willow	*Salix interior*
Sandberg's bluegrass	*Poa sandbergii*
Shortleaf pine	*Pinus echinata*
Sideoats grama	*Bouteloua curtipendula*
Slash pine	*Pinus elliottii*
Snowy buckwheat	*Eriogonum niveum*
Spike rush	*Eleocharis spp.*
Spiny hopsage	*Grayia spinosa*
Sweet gum	*Liguidambar styraciflua*
Thickspike wheatgrass	*Agropyron dasytachyum*
Threetip sagebrush	*Artemisia tripartita*
Thyme buckwheat	*Eriogonum thymoides*
Tumble mustard	*Sisymbrium altissimum*
Tupelo	*Nyssa slyvotica*
Utah juniper	*Juniperus osteosperma*
Virginia pine	*Pinus virginiana*
Watercress	*Rorippa nasturtium-aquaticum*
[Text deleted.]	
Western wheatgrass	*Agropyron smithii*
White ash	*Fraxinus americanum*
White pine	*Pinus strobus*
Willow	*Salix spp.*
Winterfat	*Eurotia lanata*

Appendix L
Socioeconomics

L.1 INTRODUCTION

Appendix L includes the supporting data used for assessing the No Action Alternative in the socioeconomics sections of this programmatic environmental impact statement. The socioeconomic analysis involved two major steps: (1) the characterization and projection of existing social, economic, and infrastructure conditions surrounding each of the candidate sites (that is, the affected environment); and (2) the evaluation of potential changes in socioeconomic conditions that could result from alternatives in the regions addressed (that is, the environmental consequences). Data and analyses used to support the assessment made for the socioeconomic sections for the No Action Alternative are presented in Tables L.1–1 to L.1–90. Data and analyses used to support the assessment of potential impacts as a result of project alternatives are contained in a separate report (Socio 1996a).

The socioeconomic environment is defined for two geographic regions: the regional economic area (REA) and the region of influence (ROI). REAs are used to assess potential effects on the regional economy, and ROIs are used to assess effects that are more localized in political jurisdictions surrounding the sites.

The REA for each site encompasses a broad market that involves trade among and between regional industrial and service sectors and is characterized by strong economic linkages between the communities in the region. These linkages determine the nature and magnitude of multiplier effects of economic activity (purchases, earnings, and employment) at each site. REAs are defined by the U.S. Bureau of Economic Analysis and consist of an economic node that serves as the center of economic activity, and the surrounding counties that are economically related and include the places of work and residences of the labor force.

Potential demographic impacts were assessed for each ROI, a smaller geographic area where the housing market and local community services would be most affected. Site-specific ROIs were identified as those counties where approximately 90 percent of the current Department of Energy and/or contractor employees reside. This residential distribution reflects existing commuting patterns and attractiveness of area communities for people employed at each site and is used to estimate the future distribution of in-migrating workers.

Table L.1–1. Department of Energy Sites' Regional Economic Areas by County

Hanford	NTS	INEL	Pantex		ORR	SRS	RFETS			LANL
Washington	**Arizona**	**Idaho**	**New Mexico**	**Texas (cont'd)**	**Tennessee**	**Georgia**	**Colorado**	**Colorado**	**Kansas**	**New Mexico**
Adams	Mohave	Bannock	Curry	Hall	Anderson	Burke	Adams	**(cont'd)**	Cheyenne	Guadalupe
Benton		Bingham	DeBaca	Hansford	Blount	Columbia	Arapahoe	Kit Carson	Gove	Mora
Chelan		Bonneville	Harding	Hartley	Campbell	Glascock	Boulder	Lake	Logan	Taos
Douglas	**Nevada**	Butte	Quay	Hemphill	Cocke	Jefferson	Chaffee	Larimer	Sheridan	San Miguel
Franklin	Clark	Clark	Roosevelt	Hutchinson	Grainger	Jenkins	Clear Creek	Lincoln	Sherman	Los Alamos
Grant	Esmeralda	Custer	Union	Lipscomb	Hamblen	Lincoln	Custer	Logan	Thomas	Santa Fe
Kittitas	Lincoln	Fremont		Moore	Hancock	McDuffie	Delta	Mesa	Wallace	Rio Arriba
Okanogan	Mineral	Jefferson		Ochiltree	Jefferson	Richmond	Denver	Moffat		
Yakima	Nye	Lemhi	**Texas**	Oldham	Knox	Warren	Douglas	Montrose		
		Madison	Armstrong	Parmer	Loudon	Wilkes	Eagle	Morgan	**Nebraska**	
		Power	Bailey	Potter	Morgan		El Paso	Ouray	Dundy	
	Utah	Teton	Carson	Randall	Roane		Elbert	Park		
	Beaver		Castro	Roberts	Scott	**South Carolina**	Fremont	Phillips		
	Garfield		Childress	Sherman	Sevier	Aiken	Garfield	Pitkin		
	Iron	**Wyoming**	Collingsworth	Wheeler	Union	Allendale	Gilpin	Rio Blanco		
	Piute	Teton	Cottle			Bamberg	Grand	Routt		
	Washington		Dallam			Barnwell	Gunnison	San Miguel		
			Deaf Smith			Edgefield	Hinsdale	Summit		
			Donley				Jackson	Teller		
			Gray				Jefferson	Washington		
								Weld		
								Yuma		

Source: DOC 1995a.

Table L.1–2. Distribution of Employees by Place of Residence in the Hanford Site Region of Influence, 1996

County/City	Number of Employees	Total Site Employment (percent)
Benton County	11,494	78.8
Kennewick	4,230	29.0
Richland	5,295	36.3
West Richland	1,109	7.6
Franklin County	1,298	8.9
Pasco	1,284	8.8
Yakima County	452	3.1
[Text deleted.]		
ROI Total	13,244	90.8

Note: City values are included within county totals.
Source: HF 1996a:2.

Table L.1–3. Distribution of Employees by Place of Residence in the Nevada Test Site Region of Influence, 1991

County/City	Number of Employees	Total Site Employment (percent)
Clark County	6,270	81.7
Henderson	357	4.7
Las Vegas	5,352	69.7
North Las Vegas	505	6.6
Nye County	1,173	15.3
ROI Total	7,443	97.0

Note: City values are included within county totals.
Source: NTS 1991a:1.

Table L.1–4. Distribution of Employees by Place of Residence in the Idaho National Engineering Laboratory Region of Influence, 1991

County/City	Number of Employees	Total Site Employment (percent)
Bannock County	342	5.3
Pocatello	317	4.9
Bingham County	576	8.9
Blackfoot	460	7.1
Bonneville County	4,893	75.7
Idaho Falls	4,750	73.5
Butte County	123	1.9
Jefferson County	419	6.5
Rigby	320	4.9
ROI Total	6,353	98.3

Note: City values are included within county totals. Employees do not include Westinghouse or ICPP. The percent of employees residing in each city and county in this table were used to analyze socioeconomic effects. These percentages differ from the updated percentages shown in paragraph 3.4.8 which did not include city data. City data is required to conduct the socioeconomic analysis.
Source: INEL 1991a:6.

Table L.1–5. Distribution of Employees by Place of Residence in the Pantex Plant Region of Influence, 1994

County/City	Number of Employees	Total Site Employment (percent)
Armstrong County	51	1.4
Carson County	191	5.4
Potter County	1,224	34.4
Amarillo	3,030	85.1
Randall County	1,943	54.6
ROI Total	3,409	95.8

Note: City values are included within county totals. Potter and Randall Counties each reflect a part of Amarillo.
Source: PX 1994a:2.

Table L.1–6. Distribution of Employees by Place of Residence in the Oak Ridge Reservation Region of Influence, 1990

County/City	Number of Employees	Total Site Employment (percent)
Anderson County	5,053	33.1
Clinton	1,035	6.8
Oak Ridge	3,292	21.6
Knox County	5,490	36.0
Knoxville	4,835	31.7
Loudon County	848	5.6
Lenoir City	638	4.2
Roane County	2,537	16.6
Harriman	802	5.3
Kingston	1,033	6.8
ROI Total	13,928	91.3

Note: City values are included within county totals.
Source: ORR 1991a:4.

Table L.1–7. Distribution of Employees by Place of Residence in the Savannah River Site Region of Influence, 1991

County/City	Number of Employees	Total Site Employment (percent)
Aiken County	9,978	51.9
Aiken	4,928	25.7
North Augusta	2,666	13.9
Allendale County	217	1.1
Bamberg County	329	1.7
Barnwell County	1,401	7.3
Columbia County	2,036	10.6
Richmond County	3,358	17.5
Augusta	2,780	14.5
ROI Total	17,319	90.1

Note: City values are included within county totals.
Source: SRS 1991a:3.

Table L.1–8. Distribution of Employees by Place of Residence in the Rocky Flats Environmental Technology Site Region of Influence, 1995

County/City	Number of Employees	Total Site Employment (percent)
Adams County	887	20.0
Westminster	637	14.4
Thornton	230	5.2
Arapahoe County	158	3.6
Boulder County	1,135	25.6
Broomfield	373	8.4
Longmont	227	5.1
Denver County	276	6.2
Jefferson County	1,559	35.2
Arvada	659	14.9
ROI Total	4,015	90.6

Note: City values are included within county totals.
Source: RFETS 1995a:1.

Table L.1–9. Distribution of Employees by Place of Residence in the Los Alamos National Laboratory Region of Influence, 1991

County/City	Number of Employees	Total Site Employment (percent)
Los Alamos County	4,697	48.3
Rio Arriba County	2,027	20.8
Espanola	944	9.7
Santa Fe County	1,851	19.0
Santa Fe	1,548	15.9
ROI Total	8,575	88.1

Note: City values are included within county totals.
Source: LANL 1991b:6.

Table L.1–10. Hanford Site Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	332,000	354,100	373,700	392,200	411,200	428,300	458,500	490,700
Total employment	301,900	322,000	339,800	356,600	374,000	389,500	416,000	446,300
Unemployment rate (percent)	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
Total personal income (thousands of dollars)	11,577,987	13,168,249	14,667,279	16,157,208	17,766,227	19,272,231	22,080,020	25,296,940
Per capita income (dollars)	18,996	20,259	21,381	22,441	23,531	24,508	26,233	28,079

Source: Census 1993k; Census 1994o; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a.

Table L.1–11. Hanford Site Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	131,00	139,700	147,400	154,700	161,700	169,000	180,900	193,600
Kennewick	48,700	52,000	54,800	57,600	60,200	62,900	67,300	72,000
Richland	36,200	38,600	40,700	42,800	44,700	46,700	50,000	53,500
West Richland	5,900	6,300	6,700	7,000	7,300	7,600	8,200	8,700
Franklin County	43,300	46,100	48,700	51,100	53,400	55,800	59,700	64,000
Pasco	23,500	25,100	26,500	27,800	29,000	30,400	32,500	34,800
Yakima County	210,400	224,400	236,800	248,500	259,700	271,400	290,500	311,000
[Text deleted.]								
ROI Total	384,700	410,200	432,900	454,300	474,800	496,200	531,100	568,600

Note: City values are included within county totals.

Source: Census 1993k; Census 1994o; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–12. Hanford Site Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	50,400	53,800	56,700	59,600	62,200	65,000	69,600	74,500
Kennewick	19,200	20,400	21,600	22,600	23,600	24,700	26,500	28,300
Richland	15,100	16,100	17,000	17,800	18,600	19,500	20,800	22,300
West Richland	2,200	2,400	2,500	2,700	2,800	2,900	3,100	3,300
Franklin County	14,800	15,700	16,600	17,400	18,200	19,100	20,400	21,800
Pasco	8,500	9,000	9,500	10,000	10,400	10,900	11,700	12,500
Yakima County	75,700	80,800	85,200	89,400	93,500	97,700	104,600	111,900
[Text deleted.]								
ROI Total	140,900	150,300	158,500	166,400	173,900	181,800	194,600	208,200

Note: City values are included within county totals.

Source: Census 1991d; Table L.1–11.

Table L.1–13. Hanford Site Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	25,494	27,198	28,702	30,115	31,489	32,882	35,198	37,674
Finley District	1,130	1,210	1,280	1,340	1,400	1,460	1,560	1,670
Kennewick District	12,340	13,160	13,880	14,570	15,230	15,910	17,030	18,230
Kiona Benton District	1,410	1,510	1,590	1,670	1,750	1,820	1,950	2,090
Patterson District	64	68	72	75	79	82	88	94
Prosser District	2,590	2,760	2,920	3,060	3,200	3,340	3,580	3,830
Richland District	7,960	8,490	8,960	9,400	9,830	10,270	10,990	11,760
Franklin County	8,927	9,524	10,049	10,550	11,031	11,522	12,324	13,195
Kahlotus District	90	96	100	110	110	120	120	130
North Franklin District	1,760	1,880	1,980	2,080	2,180	2,270	2,430	2,610
Pasco District	7,060	7,530	7,950	8,340	8,720	9,110	9,750	10,430
Star District	17	18	19	20	21	22	24	25
Yakima County	42,470	45,310	47,800	50,180	52,430	54,790	58,630	62,790
East Valley District	2,110	2,250	2,370	2,490	2,600	2,720	2,910	3,120
Grandview District	2,630	2,810	2,960	3,110	3,250	3,390	3,630	3,890
Granger District	1,100	1,180	1,240	1,310	1,360	1,420	1,520	1,630
Highland District	1,010	1,080	1,140	1,190	1,250	1,300	1,400	1,490
Mabton District	800	850	900	940	990	1,030	1,110	1,180
Mount Adams District	1,110	1,180	1,250	1,310	1,370	1,430	1,530	1,640
Naches Valley District	1,390	1,490	1,570	1,650	1,720	1,800	1,920	2,060
Selah District	3,350	3,570	3,770	3,960	4,130	4,320	4,620	4,950
Sunnyside District	4,520	4,820	5,090	5,340	5,580	5,840	6,250	6,690
Toppenish District	2,980	3,180	3,350	3,520	3,680	3,840	4,110	4,400
Union Gap District	480	520	550	570	600	630	670	720
Wapato District	3,090	3,290	3,470	3,650	3,810	3,980	4,260	4,560
West Valley District	4,130	4,400	4,640	4,870	5,090	5,320	5,700	6,100
Yakima District	12,700	13,540	14,290	15,000	15,670	16,380	17,530	18,770
Zillah District	1,070	1,150	1,210	1,270	1,330	1,390	1,480	1,590
ROI Total	76,891	82,032	86,551	90,845	94,950	99,194	106,152	113,659

Note: Bolded areas are county totals and unbolded areas are school districts.

Source: Socio 1996a; Table L.1–11.

Table L.1–14. Hanford Site Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	1,303	1,388	1,467	1,540	1,607	1,680	1,800	1,925
Finley District	57	60	64	67	70	73	78	84
Kennewick District	647	690	729	765	799	835	894	957
Kiona Benton District	66	70	74	78	85	90	91	92
Patterson District	4	4	5	5	5	5	6	6
Prosser District	139	148	156	164	171	179	192	205
Richland District	390	416	439	461	481	503	539	576
Franklin County	527	563	593	623	653	682	729	780
Kahlotus District	15	16	17	18	19	20	21	22
North Franklin District	95	102	107	112	118	123	131	141
Pasco District	415	443	467	491	513	537	574	614
Star District	2	2	2	2	3	3	3	3
Yakima County	2,247	2,396	2,527	2,654	2,773	2,897	3,102	3,318
East Valley District	110	118	124	130	136	142	152	163
Grandview District	133	142	149	157	164	171	183	196
Granger District	57	61	64	67	70	73	78	84
Highland District	54	57	60	63	66	69	74	79
Mabton District	45	48	50	53	55	57	62	66
Mount Adams District	60	64	67	71	74	77	83	88
Naches Valley District	69	73	78	81	85	89	95	102
Selah District	173	185	195	205	214	223	239	256
Sunnyside District	230	245	259	272	284	297	318	340
Toppenish District	163	174	184	193	201	210	225	241
Union Gap District	27	29	31	32	34	35	38	40
Wapato District	153	163	172	181	189	197	211	226
West Valley District	205	218	230	242	253	264	283	302
Yakima District	716	763	805	845	883	923	988	1,057
Zillah District	53	56	59	62	65	68	73	78
ROI Total	4,077	4,347	4,587	4,817	5,033	5,259	5,631	6,023

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–11.

Table L.1–15. Hanford Site Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	57	60	64	67	70	73	78	84
Kennewick	67	71	75	79	83	86	92	99
Richland	45	48	50	53	55	58	62	66
West Richland	10	11	11	12	13	13	14	15
Franklin County	21	23	24	25	26	27	29	31
Pasco	44	46	49	51	54	56	60	64
Yakima County	259	277	292	306	320	335	358	383
[Text deleted.]								
ROI Total	503	536	565	593	621	648	693	742

Note: Non-ROI cities included in county number.
Source: DOJ 1995a; Table L.1–11.

Table L.1–16. Hanford Site Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	251	268	283	297	310	324	347	371
Kennewick	58	62	65	68	71	74	80	85
Richland	46	49	51	54	56	59	63	67
West Richland	32	35	36	38	40	42	45	48
Franklin County	152	162	171	179	188	196	210	225
Pasco	84	90	95	99	104	108	116	124
Yakima County	921	982	1,036	1,088	1,137	1,188	1,272	1,361
[Text deleted.]								
ROI Total	1,544	1,648	1,737	1,823	1,906	1,991	2,133	2,281

Note: Non-ROI cities included in county number.
Source: Socio 1996a; Table L.1–11.

Table L.1–17. Hanford Site Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Benton County	48	52	54	57	60	62	67	71
Franklin County	48	51	54	56	59	61	66	70
Yakima County	53	57	60	63	68	72	72	73
ROI Average	51	54	57	60	63	66	70	75

Source: AHA 1995a; Table L.1–11.

Table L.1–18. Hanford Site Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Benton County	151	161	170	178	186	195	208	223
Franklin County	42	44	47	49	51	54	57	61
Yakima County	279	297	314	329	344	359	385	412
ROI Total	472	502	531	556	581	608	650	696

Source: AMA 1995a; Table L.1–11.

Table L.1–19. Nevada Test Site Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	625,300	731,600	822,700	910,100	991,200	1,063,900	1,183,800	1,317,200
Total employment	587,000	686,800	772,300	854,400	930,500	998,700	1,111,300	1,236,600
Unemployment rate (percent)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Total personal income (thousands of dollars)	26,000,837	35,588,677	45,005,896	55,080,114	65,335,105	75,263,852	93,188,103	115,381,024
Per capita income (dollars)	21,900	25,622	28,813	31,875	34,716	37,260	41,460	46,134

Source: Census 1993f; Census 1993y; Census 1993z; Census 1994o; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a.

Table L.1–20. Nevada Test Site Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	968,100	1,132,700	1,273,700	1,409,100	1,523,500	1,647,200	1,832,900	2,039,500
Henderson	105,200	123,100	138,500	153,200	165,600	179,100	199,300	221,700
Las Vegas	338,300	395,800	445,100	492,400	532,400	575,600	640,500	712,700
North Las Vegas	66,600	77,900	87,600	96,600	104,800	113,300	126,100	140,300
Nye County	22,600	26,400	29,700	32,800	35,500	38,400	42,700	47,500
ROI Total	990,700	1,159,100	1,303,400	1,441,900	1,559,000	1,685,600	1,875,600	2,087,000

Note: City values are included within county totals.

Source: Census 1993y; Census 1994o; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–21. Nevada Test Site Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	394,800	461,800	519,400	574,600	621,200	671,600	747,300	831,600
Henderson	40,000	46,800	52,700	58,300	63,000	68,100	75,800	84,300
Las Vegas	140,300	164,200	184,600	204,300	220,800	238,800	265,700	295,700
North Las Vegas	21,400	25,000	28,100	31,000	33,600	36,300	40,400	45,000
Nye County	8,900	10,500	11,800	13,000	14,100	15,200	16,900	18,900
ROI Total	403,700	472,300	531,200	587,600	635,300	686,800	764,200	850,500

Note: City values are included within county totals.

Source: Census 1991g; Table L.1–20.

Table L.1–22. Nevada Test Site Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	161,330	188,750	212,260	234,820	253,880	274,490	305,430	339,860
Nye County	4,300	5,030	5,660	6,260	6,770	7,320	8,150	9,060
ROI Total	165,630	193,780	217,920	241,080	260,650	281,810	313,580	348,920

Source: Socio 1996a; Table L.1–20.

Table L.1–23. Nevada Test Site Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	8,217	9,613	10,811	11,960	12,930	13,980	15,556	17,309
Nye County	249	291	327	362	391	423	471	524
ROI Total	8,466	9,904	11,138	12,322	13,321	14,403	16,027	17,833

Source: Socio 1996a; Table L.1–20.

Table L.1–24. Nevada Test Site Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	23	27	30	33	36	39	43	48
Henderson	158	185	208	230	248	269	299	333
Las Vegas	1,561	1,827	2,054	2,273	2,457	2,656	2,956	3,289
North Las Vegas	130	152	171	189	205	221	246	274
[Text deleted.]								
Nye County	74	87	98	108	117	126	141	157
ROI Total	1,946	2,278	2,561	2,833	3,063	3,311	3,685	4,101

Note: Incorporated cities in Clark County provide police protection. Non-ROI cities included within county number. Las Vegas Police Department also serves unincorporated Clark County.

Source: DOJ 1995a; Table L.1–20.

Table L.1–25. Nevada Test Site Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	925	1,082	1,216	1,347	1,455	1,573	1,750	1,948
Henderson	90	105	118	131	141	153	170	189
Las Vegas	330	386	434	481	520	562	625	696
North Las Vegas	71	83	94	103	112	121	135	150
Nye County	137	161	181	200	216	233	260	289
ROI Total	1,553	1,817	2,043	2,262	2,444	2,642	2,940	3,271

Note: Non-ROI cities are included within county number.
Source: Socio 1996a; Table L.1–20.

Table L.1–26. Nevada Test Site Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Clark County	63	74	83	92	99	107	119	133
Nye County	34	40	45	50	54	59	65	73
ROI Average	62	73	82	91	98	106	118	131

Source: AHA 1995a; Table L.1–20.

Table L.1–27. Nevada Test Site Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Clark County	1,283	1,501	1,689	1,858	2,009	2,172	2,417	2,689
Nye County	7	8	10	11	11	12	14	15
ROI Total	1,276	1,493	1,679	1,869	2,020	2,184	2,431	2,704

Source: AMA 1995a; Table L.1–20.

Table L.1–28. Idaho National Engineering Laboratory Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	151,400	161,300	168,100	174,400	181,200	188,200	200,700	214,000
Total employment	143,300	152,600	159,100	165,000	171,500	178,100	189,900	202,500
Unemployment rate (%)	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
Total personal income (thousands of dollars)	4,928,397	5,592,534	6,076,196	6,540,456	7,062,688	7,615,420	8,661,350	9,850,930
Per capita income (dollars)	17,701	18,217	18,988	19,700	20,472	21,258	22,670	24,177

Source: Census 1993n; Census 1993o; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a; INEL 1995a:1.

Table L.1–29. Idaho National Engineering Laboratory Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	71,800	76,500	79,800	82,800	86,000	89,300	95,200	101,600
Pocatello	50,300	53,500	55,800	57,900	60,200	62,500	66,600	71,100
Bingham County	41,500	44,200	46,100	47,800	49,700	51,600	55,000	58,700
Blackfoot	10,900	11,600	12,100	12,600	13,100	13,600	14,500	15,400
Bonneville County	80,200	85,500	89,100	92,400	96,000	99,700	106,400	113,400
Idaho Falls	50,600	53,900	56,100	58,200	60,500	62,900	67,000	71,500
Butte County	3,100	3,300	3,400	3,600	3,700	3,800	4,100	4,400
Jefferson County	18,700	19,900	20,700	21,500	22,300	23,200	24,700	26,400
Rigby	3,100	3,300	3,400	3,600	3,700	3,800	4,100	4,400
ROI Total	215,300	229,400	239,100	248,100	257,700	267,600	285,400	304,500

Note: City values are included within county totals.

Source: Census 1993n; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–30. Idaho National Engineering Laboratory Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	26,800	28,600	29,800	30,900	32,100	33,300	35,600	37,900
Pocatello	19,800	21,100	22,000	22,800	23,700	24,600	26,300	28,000
Bingham County	13,200	14,100	14,700	15,200	15,800	16,400	17,500	18,700
Blackfoot	4,000	4,200	4,400	4,600	4,800	4,900	5,300	5,600
Bonneville County	27,900	29,700	30,900	32,100	33,300	34,600	36,900	39,400
Idaho Falls	19,100	20,300	21,200	22,000	22,800	23,700	25,300	26,900
Butte County	1,100	1,200	1,300	1,300	1,400	1,400	1,500	1,600
Jefferson County	5,600	6,000	6,300	6,500	6,700	7,000	7,500	8,000
Rigby	1,100	1,100	1,200	1,200	1,300	1,300	1,400	1,500
ROI Total	74,600	79,600	83,000	86,000	89,300	92,700	99,000	105,600

Note: City values are included within county totals.
Source: Census 1991n; Table L.1–29.

Table L.1–31. Idaho National Engineering Laboratory Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	15,930	16,970	17,690	18,360	19,060	19,800	21,120	22,530
Marrsh Valley	1,740	1,850	1,930	2,010	2,080	2,160	2,310	2,460
Pocatello	14,190	15,120	15,760	16,350	16,980	17,640	18,810	20,070
Bingham County	11,730	12,510	13,040	13,540	14,050	14,590	15,570	16,610
Aberdeen	1,010	1,080	1,120	1,170	1,210	1,260	1,340	1,430
Blackfoot	4,570	4,870	5,080	5,270	5,470	5,680	6,060	6,460
Firth	1,140	1,220	1,270	1,320	1,370	1,420	1,520	1,620
Snake River	2,590	2,760	2,880	2,990	3,100	3,220	3,440	3,670
Shelley	2,420	2,580	2,690	2,790	2,900	3,010	3,210	3,430
Bonneville County	19,300	20,560	21,430	22,230	23,100	23,990	25,580	27,290
Bonneville	7,780	8,290	8,640	8,960	9,310	9,670	10,310	11,000
Idaho Falls	11,420	12,170	12,680	13,160	13,670	14,200	15,140	16,150
Swan Valley	100	100	110	110	120	120	130	140
Butte County	740	790	820	850	890	920	980	1,050
Arco	740	790	820	850	890	920	980	1,050
Jefferson County	5,760	6,130	6,400	6,640	6,890	7,160	7,630	8,150
Jefferson	4,230	4,500	4,690	4,870	5,060	5,250	5,600	5,980
Ririe	760	810	850	880	910	950	1,010	1,080
West Jefferson	770	820	860	890	920	960	1,020	1,090
ROI Total	53,460	56,960	59,380	61,620	63,990	66,460	70,880	75,630

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–29.

Table L.1–32. Idaho National Engineering Laboratory Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	872	929	968	1,004	1,043	1,084	1,156	1,233
Marsh Valley	105	112	117	121	126	131	140	149
Pocatello	767	817	851	883	917	953	1,016	1,084
Bingham County	629	671	697	724	753	782	834	889
Aberdeen	60	64	66	69	72	74	79	84
Blackfoot	264	282	293	304	316	329	350	374
Firth	61	65	67	70	73	76	81	86
Snake River	135	143	150	155	161	167	179	190
Shelley	109	117	121	126	131	136	145	155
Bonneville County	1,043	1,110	1,159	1,202	1,248	1,297	1,383	1,474
Bonneville	429	457	477	495	514	534	569	607
Idaho Falls	609	648	676	701	728	757	807	860
Swan Valley	5	5	6	6	6	6	7	7
Butte County	46	49	51	52	55	57	60	64
Arco	46	49	51	52	55	57	60	64
Jefferson County	300	320	333	344	359	373	397	424
Jefferson	215	229	238	247	257	267	285	304
Ririe	39	42	44	45	47	49	52	56
West Jefferson	46	49	51	52	55	57	60	64
ROI Total	2,890	3,079	3,208	3,326	3,458	3,593	3,830	4,084

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–29.

Table L.1–33. Idaho National Engineering Laboratory Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	55	58	61	63	65	68	72	77
Pocatello	80	85	89	92	96	99	106	113
Bingham County	39	42	44	45	47	49	52	56
Blackfoot	19	20	21	22	23	24	26	27
Bonneville County	47	50	52	54	56	58	62	66
Idaho Falls	83	88	92	96	99	103	110	117
Butte County	4	4	4	5	5	5	5	6
Jefferson County	11	12	12	13	13	14	15	16
Rigby	6	6	7	7	7	8	8	9
ROI Total	344	365	382	397	411	428	456	487

Source: DOJ 1995a; Table L.1–29.

Table L.1–34. Idaho National Engineering Laboratory Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	50	53	56	58	60	62	66	71
Pocatello	71	76	79	82	85	88	94	100
Bingham County	56	60	62	65	67	70	74	79
Blackfoot	40	43	44	46	48	50	53	57
Bonneville County	35	37	39	40	42	44	46	49
Idaho Falls	88	94	98	101	105	109	117	124
Butte County	23	25	26	26	28	29	30	33
Jefferson County	90	96	100	104	108	112	119	127
Rigby	12	13	13	14	14	15	16	17
ROI Total	465	497	517	536	557	579	615	657

Source: Socio 1996a; Table L.1–29.

Table L.1–35. Idaho National Engineering Laboratory Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Bannock County	49	52	54	56	58	60	64	69
Bingham County	62	66	68	71	74	77	82	87
Bonneville County	50	53	55	57	59	62	66	70
Butte County	NA	NA	NA	NA	NA	NA	NA	NA
Jefferson County	NH	NH	NH	NH	NH	NH	NH	NH
ROI Average	51	54	57	59	61	63	68	72

Note: NA=not available. Some hospitals in Butte County unable to provide occupancy data; NH=no hospitals are located in Jefferson County.

Source: AHA 1995a; Table L.1–29.

Table L.1–36. Idaho National Engineering Laboratory Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Bannock County	112	120	125	129	135	140	149	159
Bingham County	21	23	24	24	25	26	28	30
Bonneville County	131	139	145	150	156	162	173	185
Butte County	0	0	0	0	0	0	0	0
Jefferson County	3	3	3	3	4	4	4	4
ROI Total	267	285	297	306	320	332	354	378

Source: AMA 1995a; Table L.1–29.

Table L.1–37. Pantex Plant Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	229,100	233,000	235,500	239,000	243,000	247,700	257,300	267,300
Total employment	218,100	221,800	224,200	227,500	231,300	235,800	244,900	254,400
Unemployment rate (percent)	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
Total personal income (thousands of dollars)	8,942,433	9,251,512	9,450,250	9,732,031	10,059,136	10,450,770	11,276,590	12,167,609
Per capita income (dollars)	19,435	19,768	19,979	20,275	20,613	21,010	21,825	22,671

Source: Census 1993m; Census 1993w; Census 1994o; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1995a.

Table L.1–38. Pantex Plant Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	2,100	2,100	2,100	2,200	2,200	2,300	2,300	2,400
Carson County	6,600	6,700	6,800	6,900	7,000	7,100	7,400	7,700
Potter County	103,300	105,000	106,200	107,700	109,700	111,600	116,000	120,500
Amarillo	165,600	168,400	170,200	172,800	175,900	179,000	186,000	193,200
Randall County	94,400	96,000	97,100	98,500	100,300	102,100	106,000	110,200
ROI Total	206,400	209,800	212,200	215,300	219,200	223,100	231,700	240,800

Note: Amarillo is divided across Potter and Randall Counties. The population shown for Amarillo is for the whole city. Potter and Randall County totals represent their share of Amarillo.

Source: Census 1993w; Census 1994o; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–39. Pantex Plant Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	800	800	800	900	900	900	900	1,000
Carson County	2,600	2,600	2,700	2,700	2,800	2,800	2,900	3,000
Potter County	43,300	44,000	44,500	45,100	45,900	46,800	48,600	50,500
Amarillo	69,600	70,800	71,600	72,700	74,000	75,300	78,200	81,200
Randall County	38,700	39,300	39,700	40,300	41,100	41,800	43,400	45,100
ROI Total	85,400	86,700	87,700	89,000	90,700	92,300	95,800	99,600

Note: Amarillo is divided across Potter and Randall Counties. The value shown for Amarillo is for the whole city. Potter and Randall County totals each represent their share of Amarillo.

Source: Census 1991m; Table L.1–38.

Table L.1–40. Pantex Plant Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	400	410	410	420	430	440	450	470
Claude	400	410	410	420	430	440	450	470
Carson County	1,430	1,450	1,470	1,490	1,520	1,550	1,610	1,670
Groom	230	230	240	240	240	250	260	270
Panhandle	730	740	750	760	780	790	820	850
White Deer	470	480	480	490	500	510	530	550
Potter County	2,390	2,440	2,460	2,500	2,560	2,590	2,700	2,810
Bushland	380	390	390	400	410	410	430	450
Highland Park	690	700	710	720	740	750	780	810
River Road	1,320	1,350	1,360	1,380	1,410	1,430	1,490	1,550
Amarillo	29,020	29,520	29,840	30,280	30,820	31,380	32,590	33,860
Randall County	6,480	6,590	6,660	6,760	6,880	7,000	7,270	7,550
Canyon	6,480	6,590	6,660	6,760	6,880	7,000	7,270	7,550
ROI Total	39,720	40,410	40,840	41,450	42,210	42,960	44,620	46,360

Note: Amarillo School District values not included within county totals; bolded areas are county totals, and unbolded areas are school districts.

Source: Socio 1996a; Table L.1–38.

Table L.1–41. Pantex Plant Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	33	34	34	35	35	36	37	39
Claude	33	34	34	35	35	36	37	39
Carson County	122	124	126	128	130	133	137	142
Groom	20	20	21	21	21	22	23	23
Panhandle	59	60	61	62	63	64	66	69
White Deer	43	44	44	45	46	47	48	50
Potter County	165	169	171	173	176	179	185	194
Bushland	27	28	28	28	29	29	30	32
Highland Park	57	58	59	60	61	62	64	67
River Road	81	83	84	85	86	88	91	95
Amarillo	1,746	1,776	1,795	1,821	1,854	1,887	1,961	2,037
Randall County	372	379	383	388	395	402	418	434
Canyon	372	379	383	388	395	402	418	434
ROI Total	2,438	2,482	2,509	2,545	2,590	2,637	2,738	2,846

Note: Amarillo School District values not included within county totals; bolded areas are county totals, and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–38.

Table L.1–42. Pantex Plant Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	3	3	3	3	3	3	3	4
Carson County	5	5	5	5	5	5	6	6
Potter County	126	129	130	132	134	137	142	147
Amarillo	254	258	261	265	270	274	285	296
Randall County	76	78	78	80	81	82	86	89
ROI Total	463	473	477	485	493	501	522	542

Note: Amarillo City values not included within county totals. Non-ROI cities included within county numbers.
Source: DOJ 1995a; Table L.1–38.

Table L.1–43. Pantex Plant Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	39	40	41	41	42	43	44	46
Carson County	90	92	93	94	96	98	101	105
Potter County	0	0	0	0	0	0	0	0
Amarillo	214	217	220	223	227	231	240	249
Randall County	69	70	71	72	74	75	78	81
ROI Total	412	419	425	430	439	447	463	481

Note: Amarillo City values not included within county totals. Non-ROI cities included within county numbers.
Source: Socio 1996a; Table L.1–38.

Table L.1–44. Pantex Plant Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Armstrong County	NH	NH	NH	NH	NH	NH	NH	NH
Carson County	NH	NH	NH	NH	NH	NH	NH	NH
Potter County	56	57	58	59	60	61	63	66
Randall County	32	33	33	33	34	35	36	37
ROI Average	56	57	57	58	59	60	62	65

Note: NH=No hospitals located in Armstrong or Carson Counties.
Source: AHA 1995a; Table L.1–38.

Table L.1–45. Pantex Plant Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Armstrong County	0	0	0	0	0	0	0	0
Carson County	0	0	0	0	0	0	0	0
Potter County	396	403	407	413	421	428	445	462
Randall County	12	12	12	13	13	13	14	14
ROI Total	408	415	419	426	434	441	459	476

Source: AMA 1995a; Table L.1–38.

Table L.1–46. Oak Ridge Reservation Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	482,200	512,900	537,400	562,400	587,400	610,900	653,400	698,900
Total employment	458,800	488,100	511,400	535,200	558,900	681,300	621,800	665,000
Unemployment rate (percent)	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
Total personal income (thousands of dollars)	16,482,992	18,654,590	20,477,380	22,427,539	24,466,384	26,460,927	30,273,609	34,635,650
Per capita income (dollars)	18,190	19,351	20,275	21,218	22,162	23,047	24,652	26,368

Source: Census 1993b; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a; OR LMES 1995e.

Table L.1–47. Oak Ridge Reservation Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	72,100	76,700	80,400	84,100	87,700	91,400	97,700	104,500
Clinton	10,400	11,000	11,500	12,100	12,600	13,100	14,000	15,000
Oak Ridge	28,600	30,400	31,800	33,300	34,700	36,200	38,700	41,400
Knox County	361,900	385,000	403,400	422,100	440,000	458,500	490,500	524,600
Knoxville	171,400	182,400	191,100	200,000	208,400	217,200	232,300	248,500
Loudon County	35,500	37,800	39,600	41,400	43,200	45,000	48,100	51,500
Lenoir City	8,800	9,300	9,800	10,200	10,700	11,100	11,900	12,700
Roane County	49,100	52,200	54,700	57,300	59,700	62,200	66,600	71,200
Harriman	7,300	7,700	8,100	8,500	8,900	9,200	9,900	10,600
Kingston	5,200	5,500	5,800	6,000	6,300	6,600	7,000	7,500
ROI Total	518,600	551,700	578,100	604,900	630,600	657,100	702,900	751,800

Note: City values are included within county totals.
Source: Census 1993b; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–48. Oak Ridge Reservation Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	30,000	31,900	33,500	35,000	36,500	38,000	40,700	43,500
Clinton	4,500	4,800	5,000	5,300	5,500	5,700	6,100	6,600
Oak Ridge	12,000	12,700	13,300	13,900	14,500	15,200	16,200	17,300
Knox County	150,600	160,200	167,900	175,700	183,100	190,800	204,100	218,300
Knoxville	76,900	81,800	85,700	89,700	93,500	97,500	104,200	111,500
Loudon County	14,200	15,100	15,900	16,600	17,300	18,000	19,300	20,600
Lenoir City	3,800	4,000	4,200	4,400	4,600	4,800	5,100	5,500
Roane County	19,900	21,200	22,200	23,200	24,200	25,200	27,000	28,800
Harriman	3,100	3,300	3,500	3,700	3,800	4,000	4,300	4,500
Kingston	2,300	2,500	2,600	2,700	2,800	2,900	3,100	3,400
ROI Total	214,700	228,400	239,500	250,500	261,100	272,000	291,100	311,200

Note: City values are included within county totals.
Source: Census 1991c; Table L.1–47.

Table L.1–49. Oak Ridge Reservation Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	12,900	13,720	14,380	15,050	15,690	16,340	17,480	18,710
Anderson County	6,890	7,320	7,670	8,030	8,370	8,720	9,330	9,980
Clinton City	1,180	1,260	1,320	1,380	1,440	1,500	1,600	1,720
Oak Ridge	4,830	5,140	5,390	5,640	5,880	6,120	6,550	7,010
Knox County	56,260	59,850	62,700	65,620	68,390	71,280	76,240	81,550
Knox County	56,260	59,850	62,700	65,620	68,390	71,280	76,240	81,550
Loudon County	6,510	6,920	7,260	7,580	7,910	8,250	8,820	9,430
Loudon County	4,590	4,880	5,120	5,350	5,580	5,820	6,220	6,650
Lenoir City	1,920	2,040	2,140	2,230	2,330	2,430	2,600	2,780
Roane County	7,670	8,160	8,550	8,950	9,320	9,710	10,390	11,120
Roane County	5,950	6,330	6,630	6,940	7,230	7,530	8,060	8,620
Harriman	1,720	1,830	1,920	2,010	2,090	2,180	2,330	2,500
ROI Total	83,340	88,650	91,890	97,200	101,310	105,580	112,930	120,810

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–47.

Table L.1–50. Oak Ridge Reservation Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	912	971	1,017	1,064	1,109	1,156	1,237	1,322
Anderson County	486	517	542	567	591	616	659	704
Clinton City	78	83	87	91	95	99	106	113
Oak Ridge	348	371	388	406	423	441	472	505
Knox County	3,347	3,561	3,731	3,904	4,069	4,241	4,536	4,852
Knox County	3,347	3,561	3,731	3,904	4,069	4,241	4,536	4,852
Loudon County	389	414	434	455	473	494	528	565
Loudon County	278	296	310	325	338	353	377	404
Lenoir City	111	118	124	130	135	141	151	161
Roane County	484	516	540	566	590	615	658	703
Roane County	363	387	405	424	442	461	493	527
Harriman	121	129	135	142	148	154	165	176
ROI Total	5,132	5,462	5,722	5,989	6,241	6,506	6,959	7,442

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–47.

Table L.1–51. Oak Ridge Reservation Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	124	131	138	144	150	157	167	179
Clinton	16	17	18	19	20	21	22	23
Oak Ridge	50	53	55	58	60	63	67	72
Knox County	240	255	267	280	292	304	325	348
Knoxville	341	363	380	398	415	432	462	495
Loudon County	42	44	46	48	50	53	56	60
Lenoir City	14	15	16	17	17	18	19	21
Roane County	49	52	54	57	59	62	66	70
Harriman	13	14	15	15	16	17	18	19
Kingston	8	9	9	9	10	10	11	12
ROI Total	897	953	998	1,045	1,089	1,137	1,213	1,299

Source: DOJ 1995a; Socio 1996a; Table L.1–47.

Table L.1–52. Oak Ridge Reservation Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	183	195	204	213	222	232	248	265
Clinton	16	17	18	19	19	20	22	23
Oak Ridge	46	49	51	54	56	58	62	67
Knox County	200	213	223	233	243	253	271	290
Knoxville	357	380	398	416	434	452	484	518
Loudon County	138	147	154	161	168	175	187	200
Lenoir City	15	16	17	17	18	19	20	22
Roane County	110	117	123	128	134	139	149	159
Harriman	18	19	20	21	22	23	24	26
Kingston	37	39	41	43	45	47	50	54
ROI Total	1,120	1,192	1,249	1,305	1,361	1,418	1,517	1,624

Source: Socio 1996a; Table L.1–47.

Table L.1–53. Oak Ridge Reservation Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Anderson County	66	70	74	77	80	84	90	96
Knox County	66	70	73	77	80	83	89	95
Loudon County	32	34	36	38	39	41	44	47
Roane County	52	55	58	61	63	66	71	76
ROI Average	65	69	72	75	78	82	87	93

Source: AHA 1995a; Table L.1–47.

Table L.1–54. Oak Ridge Reservation Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Anderson County	147	156	164	171	178	186	199	213
Knox County	1,123	1,194	1,251	1,310	1,365	1,423	1,522	1,628
Loudon County	24	26	27	28	30	31	33	35
Roane County	28	30	32	33	34	36	38	41
ROI Total	1,322	1,406	1,474	1,542	1,607	1,676	1,792	1,917

Source: AMA 1995a; Table L.1–47.

Table L.1–55. Savannah River Site Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	260,400	275,600	288,600	302,500	316,300	329,700	354,000	380,000
Total employment	242,900	257,000	269,200	282,100	295,100	307,600	330,200	354,500
Unemployment rate (percent)	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Total personal income (thousands of dollars)	10,070,574	11,281,795	12,370,855	13,590,502	14,867,480	16,152,064	18,615,578	21,454,828
Per capita income (dollars)	17,332	18,334	19,209	20,134	21,059	21,950	23,564	25,297

Source: Census 1993c; Census 1993e; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a; SRS 1995a:2.

Table L.1–56. Savannah River Site Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	133,600	141,400	148,000	155,200	162,000	169,200	181,600	195,000
Aiken	25,200	26,700	27,900	29,300	30,600	31,900	34,300	36,800
North Augusta	17,800	18,900	19,800	20,700	21,600	22,600	24,200	26,000
Allendale County	11,600	11,500	11,700	12,300	12,800	13,400	14,400	15,500
Bamberg County	16,600	16,300	16,700	17,500	18,300	19,200	20,600	22,200
Barnwell County	21,700	22,900	24,000	25,200	26,300	27,400	29,500	31,600
Columbia County	80,800	85,600	89,600	93,900	98,000	102,400	109,900	118,000
Richmond County	193,200	185,200	194,000	203,500	212,900	222,700	239,600	257,900
Augusta	42,900	41,300	43,100	45,300	47,300	49,500	53,300	57,300
ROI Total	457,500	462,900	484,000	507,600	530,300	554,300	595,600	640,200

Note: City values are included within county totals.

Source: Census 1993c; Census 1993e; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–57. Savannah River Site Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	52,000	55,000	57,600	60,400	63,000	65,800	70,600	75,800
Aiken	10,400	11,000	11,500	12,100	12,600	13,200	14,200	15,200
North Augusta	7,700	8,200	8,600	9,000	9,400	9,800	10,500	11,300
Allendale County	3,900	3,900	3,900	4,100	4,300	4,500	4,800	5,200
Bamberg County	5,700	5,600	5,700	6,000	6,300	6,600	7,100	7,600
Barnwell County	7,900	8,400	8,700	9,200	9,600	10,000	10,700	11,500
Columbia County	27,700	29,400	30,800	32,200	33,700	35,100	37,700	40,500
Richmond County	74,200	71,100	74,500	78,200	81,800	85,500	92,000	99,100
Augusta	19,300	18,600	19,400	20,400	21,300	22,300	24,000	25,800
ROI Total	171,400	173,400	181,200	190,100	198,700	207,500	222,900	239,700

Note: City values are included within county totals.
Source: Census 1991a; Census 1991b; Table L.1–56.

Table L.1–58. Savannah River Site Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	25,610	27,110	28,380	29,750	31,060	32,430	34,820	37,380
Aiken County	25,610	27,110	28,380	29,750	31,060	32,430	34,820	37,380
Allendale County	2,340	2,310	2,350	2,460	2,570	2,690	2,900	3,120
Allendale County	2,340	2,310	2,350	2,460	2,570	2,690	2,900	3,120
Bamberg County	3,130	3,080	3,160	3,310	3,460	3,620	3,900	4,190
District #1	1,820	1,790	1,840	1,930	2,010	2,110	2,270	2,440
District #2	1,310	1,290	1,320	1,380	1,450	1,510	1,630	1,750
Barnwell County	4,990	5,290	5,540	5,810	6,060	6,320	6,790	7,280
District #19	1,270	1,350	1,410	1,480	1,540	1,610	1,730	1,850
District #29	1,030	1,090	1,140	1,200	1,250	1,300	1,400	1,500
District #45	2,690	2,850	2,990	3,130	3,270	3,410	3,660	3,930
Columbia County	16,260	17,210	18,020	18,890	19,720	20,590	22,110	23,730
Columbia County	16,260	17,210	18,020	18,890	19,720	20,590	22,110	23,730
Richmond County	34,400	32,990	34,550	36,240	37,910	39,660	42,670	45,920
Richmond County	34,400	32,990	34,550	36,240	37,910	39,660	42,670	45,920
ROI Total	86,730	87,990	92,000	96,460	100,780	105,310	113,190	121,620

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–56.

Table L.1–59. Savannah River Site Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	1,345	1,424	1,491	1,563	1,632	1,704	1,829	1,963
Aiken County	1,345	1,424	1,491	1,563	1,632	1,704	1,829	1,963
Allendale County	159	158	160	168	176	184	198	213
Allendale County	159	158	160	168	176	184	198	213
Bamberg County	224	221	226	237	248	259	279	300
District #1	124	122	125	131	137	143	154	166
District #2	100	99	101	106	111	116	125	134
Barnwell County	299	316	331	347	362	378	405	436
District #19	76	80	84	88	92	96	103	111
District #29	68	72	75	79	82	86	92	99
District #45	155	164	172	180	188	196	210	226
Columbia County	905	958	1,003	1,052	1,098	1,146	1,231	1,321
Columbia County	905	958	1,003	1,052	1,098	1,146	1,231	1,321
Richmond County	2,034	1,950	2,043	2,143	2,242	2,345	2,523	2,715
Richmond County	2,034	1,950	2,043	2,143	2,242	2,345	2,523	2,715
ROI Total	4,966	5,027	5,254	5,510	5,758	6,016	6,465	6,948

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–56.

Table L.1–60. Savannah River Site Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	100	106	111	116	121	127	136	146
Aiken	83	88	92	96	101	105	113	121
North Augusta	49	51	54	56	59	61	66	71
Allendale County	19	19	19	20	21	22	23	25
Bamberg County	24	23	24	25	26	28	30	32
Barnwell County	36	39	40	42	44	46	50	53
Columbia County	154	163	170	179	186	195	209	224
Richmond County	320	307	321	337	353	369	397	427
Augusta	167	161	168	176	184	193	207	223
ROI Total	952	957	999	1,047	1,095	1,146	1,231	1,322

Source: DOJ 1995a; Table L.1–56.

Table L.1–61. Savannah River Site Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	375	397	416	436	455	475	510	547
Aiken	100	106	111	116	121	127	136	146
North Augusta	45	48	50	52	55	57	61	66
Allendale County	82	81	82	86	90	94	102	109
Bamberg County	155	152	156	164	171	179	193	207
Barnwell County	90	95	100	105	109	114	122	131
Columbia County	196	207	217	228	238	248	266	286
Richmond County	182	174	183	192	201	210	226	243
Augusta	138	133	139	146	152	159	171	184
ROI Total	1,363	1,393	1,454	1,525	1,592	1,663	1,787	1,919

Source: Socio 1996a; Table L.1–56.

Table L.1–62. Savannah River Site Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Aiken County	NA	NA	NA	NA	NA	NA	NA	NA
Allendale County	67	66	67	71	74	77	83	90
Bamberg County	72	71	73	76	80	84	90	97
Barnwell County	47	50	52	55	57	60	64	69
Columbia County	NH	NH	NH	NH	NH	NH	NH	NH
Richmond County	61	58	61	64	67	70	75	81
ROI Average	65	65	68	72	75	78	84	90

Note: NA=not available. Some hospitals in Aiken County are unable to provide occupancy data. NH=No hospitals are located in Columbia County.

Source: AHA 1995a; Table L.1–56.

Table L.1–63. Savannah River Site Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Aiken County	145	153	160	168	175	183	197	211
Allendale County	6	6	6	6	7	7	7	8
Bamberg County	8	8	8	8	9	9	10	11
Barnwell County	8	9	9	9	10	10	11	12
Columbia County	212	225	235	247	258	269	289	310
Richmond County	971	931	975	1,023	1,070	1,119	1,204	1,296
ROI Total	1,350	1,332	1,393	1,461	1,529	1,597	1,458	1,848

Source: AMA 1995a; Table L.1–56.

Table L.1–64. Rocky Flats Environmental Technology Site Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	1,900,800	2,070,300	2,219,300	2,362,800	2,502,300	2,629,900	2,854,200	3,097,500
Total employment	1,822,900	1,985,400	2,128,300	2,265,900	2,399,700	2,522,100	2,737,200	2,970,500
Unemployment rate (percent)	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
Total personal income (thousands of dollars)	77,373,382	91,785,863	105,476,299	119,552,501	134,090,993	148,119,250	174,451,599	205,465,262
Per capita income (dollars)	22,721	24,747	26,528	28,243	29,911	31,437	34,117	37,025

Source: Census 1993t; Census 1993u; Census 1993v; Census 1995a; CO DIS 1994a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a; RFETS 1995a:1.

Table L.1–65. Rocky Flats Environmental Technology Site Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	300,200	333,600	363,700	392,300	418,000	445,400	489,200	537,300
Westminster	88,800	98,800	107,600	116,100	123,700	131,800	144,800	159,000
Thornton	64,400	71,600	78,000	84,200	89,700	95,500	104,900	115,300
Arapahoe County	452,500	503,000	548,200	591,400	630,200	671,400	737,500	810,000
Boulder County	254,800	283,200	308,700	333,000	354,800	378,100	415,300	456,100
Broomfield	28,000	31,100	33,900	36,600	39,000	41,500	45,600	50,100
Longmont	57,400	63,800	69,600	75,100	80,000	85,200	93,600	102,800
Denver County	497,100	507,900	514,600	522,200	529,900	537,800	553,700	570,000
Jefferson County	487,100	541,400	590,100	636,600	678,300	722,800	793,800	871,900
Arvada	97,400	108,300	118,000	127,300	135,700	144,600	158,800	174,400
ROI Total	1,991,700	2,169,100	2,325,300	2,475,500	2,611,200	2,755,500	2,989,500	3,245,300

Note: Cities split across county lines were analyzed in the county where a majority of the population resides. All city values are included within county totals.
Source: Census 1993v; Census 1995a; CO DIS 1994a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–66. Rocky Flats Environmental Technology Site Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	118,100	131,300	143,100	154,400	164,500	155,900	192,600	211,500
Westminster	35,100	39,000	42,500	45,800	48,900	44,800	57,200	62,800
Thornton	23,800	26,400	28,800	31,100	33,100	30,600	38,700	42,600
Arapahoe County	192,400	213,900	233,100	251,500	268,000	251,700	313,600	344,400
Boulder County	103,300	114,800	125,200	135,000	143,900	135,800	168,400	184,900
Broomfield	10,300	11,400	12,500	13,500	14,300	9,000	16,800	18,400
Longmont	22,600	25,100	27,400	29,500	31,500	30,200	36,800	40,500
Denver County	247,600	253,000	256,300	260,100	264,000	339,000	275,800	283,900
Jefferson County	193,800	215,400	234,800	253,300	269,900	255,000	315,900	346,900
Arvada	36,300	40,300	43,900	47,400	50,500	47,600	59,100	64,900
ROI Total	855,200	928,400	992,500	1,054,300	1,110,300	1,137,400	1,266,300	1,371,600

Note: City values are included within county totals.
Source: Census 1991k; Table L.1–65.

Table L.1–67. Rocky Flats Environmental Technology Site Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	58,990	65,590	71,460	77,100	82,170	87,540	96,160	105,610
Adams County	6,540	7,270	7,920	8,550	9,110	9,710	10,660	11,710
Bennet	1,050	1,170	1,270	1,370	1,460	1,560	1,710	1,880
Brighton	4,410	4,900	5,340	5,760	6,140	6,540	7,190	7,890
Mappleton	4,990	5,550	6,040	6,520	6,950	7,400	8,130	8,930
Northglenn-Thornton	27,020	30,040	32,740	35,320	37,640	40,100	44,050	48,380
Strasburg	220	250	270	290	310	330	360	400
Westminster City	14,760	16,410	17,880	19,290	20,560	21,900	24,060	26,420
Arapahoe County	87,180	96,920	105,640	113,950	121,430	129,370	142,100	156,070
Adams-Arapahoe/Aurora	27,990	31,110	33,910	36,580	38,980	41,530	45,620	50,100
Byers	380	420	460	490	530	560	610	670
Cherry Creek	36,210	40,250	43,870	47,330	50,430	53,730	59,010	64,820
Englewood	4,370	4,860	5,290	5,710	6,080	6,480	7,120	7,820
Littleton	16,020	17,810	19,420	20,940	22,320	23,780	26,120	28,690
Sheridan	2,020	2,250	2,450	2,650	2,820	3,000	3,300	3,620
Deer Trail	190	220	240	250	270	290	320	350
Boulder County	41,570	46,210	50,360	54,330	57,890	61,680	67,750	74,410
Boulder Valley	25,170	27,980	30,490	32,900	35,050	37,350	41,020	45,050
St. Vrain	16,400	18,230	19,870	21,430	22,840	24,330	26,730	29,360
Denver County	63,220	64,590	65,440	66,410	67,400	68,400	70,420	72,490
Denver County	63,220	64,590	65,440	66,410	67,400	68,400	70,420	72,490
Jefferson County	85,880	95,470	104,050	112,250	119,610	127,440	139,980	153,740
Jefferson County	85,880	95,470	104,050	112,250	119,610	127,440	139,980	153,740
ROI Total	336,840	368,780	396,950	424,040	448,500	474,430	516,410	562,320

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–65.

Table L.1–68. Rocky Flats Environmental Technology Site Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	3,034	3,374	3,678	3,967	4,226	4,504	4,946	5,433
Adams County	318	354	386	416	443	473	519	570
Bennet	68	76	83	89	95	101	111	122
Brighton	248	276	300	324	345	368	404	444
Mapleton	334	371	404	436	465	495	544	597
Northglenn-Thornton	1,404	1,561	1,702	1,836	1,956	2,084	2,289	2,514
Strasburg	17	19	21	23	24	26	28	31
Westminster City	645	717	782	843	898	957	1,051	1,155
Arapahoe County	5,202	5,783	6,303	6,800	7,246	7,721	8,478	9,313
Adams-Arapahoe/Aurora	1,523	1,693	1,845	1,990	2,121	2,260	2,482	2,726
Byers	30	33	36	39	41	44	48	53
Cherry Creek	2,245	2,496	2,721	2,935	3,127	3,332	3,660	4,020
Englewood	278	309	336	363	387	412	452	497
Littleton	995	1,106	1,206	1,301	1,386	1,477	1,622	1,781
Sheridan	108	120	131	141	151	161	176	194
Deer Trail	23	26	28	31	33	35	38	42
Boulder County	2,220	2,468	2,689	2,901	3,091	3,295	3,618	3,974
Boulder Valley	1,403	1,560	1,700	1,834	1,954	2,083	2,287	2,512
St. Vrain	817	908	989	1,067	1,137	1,212	1,331	1,462
Denver County	3,671	3,751	3,800	3,856	3,914	3,972	4,089	4,209
Denver County	3,671	3,751	3,800	3,856	3,914	3,972	4,089	4,209
Jefferson County	3,624	4,029	4,391	4,737	5,048	5,378	5,907	6,488
Jefferson County	3,624	4,029	4,391	4,737	5,048	5,378	5,907	6,488
ROI Total	17,751	19,405	20,861	22,261	23,525	24,870	27,038	29,417

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–65.

Table L.1–69. Rocky Flats Environmental Technology Site Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	142	158	172	185	198	211	231	254
Westminster	122	136	148	160	171	182	200	219
Thornton	90	100	109	117	125	133	146	161
Arapahoe County	1,001	1,113	1,213	1,309	1,394	1,486	1,632	1,792
Boulder County	181	201	219	236	252	268	294	323
Broomfield	46	51	56	60	64	68	75	82
Longmont	84	93	101	109	117	124	136	150
Denver County	1,388	1,418	1,437	1,458	1,480	1,502	1,546	1,591
Jefferson County	698	776	846	912	972	1,036	1,138	1,250
Arvada	119	133	145	156	166	177	195	214
ROI Total	3,871	4,179	4,446	4,702	4,939	5,187	5,593	6,036

Source: DOJ 1995a; Socio 1996a; Table L.1–65.

Table L.1–70. Rocky Flats Environmental Technology Site Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	1,396	1,552	1,691	1,825	1,944	2,072	2,275	2,499
Westminster	123	137	149	161	171	183	200	220
Thornton	89	99	108	116	124	132	145	159
Arapahoe County	953	1,059	1,155	1,246	1,327	1,414	1,553	1,706
Boulder County	787	875	954	1,029	1,096	1,168	1,283	1,409
Broomfield	39	43	47	51	54	58	64	70
Longmont	68	76	82	89	95	101	111	122
Denver County	875	894	906	919	933	947	975	1,003
Jefferson County	878	976	1,064	1,148	1,223	1,303	1,431	1,572
Arvada	200	222	242	261	279	297	326	358
ROI Total	5,408	5,933	6,398	6,845	7,246	7,675	8,363	9,118

Source: Socio 1996a; Table L.1–65.

Table L.1–71. Rocky Flats Environmental Technology Site Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Adams County	23	25	28	30	32	34	37	41
Arapahoe County	50	55	60	65	69	74	81	89
Boulder County	51	57	62	67	71	76	83	92
Denver County	49	60	61	62	63	64	66	68
Jefferson County	45	50	54	59	63	67	73	80
ROI Average	56	61	65	70	73	78	84	91

Source: AHA 1995a; Table L.1–65.

Table L.1–72. Rocky Flats Environmental Technology Site Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Adams County	474	526	574	619	660	703	772	848
Arapahoe County	787	875	953	1,029	1,096	1,168	1,283	1,409
Boulder County	557	619	675	728	776	827	908	998
Denver County	2,668	2,726	2,762	2,803	2,844	2,886	2,972	3,059
Jefferson County	599	666	726	783	834	889	976	1,073
ROI Total	5,085	5,412	5,690	5,962	6,210	6,473	6,911	7,387

Source: AMA 1995a; L.1–65.

Table L.1–73. Los Alamos National Laboratory Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	119,400	130,000	138,900	147,200	156,000	163,600	176,900	191,100
Total employment	112,100	122,000	130,300	138,100	146,400	153,500	165,900	179,300
Unemployment rate (percent)	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
Total personal income (thousands of dollars)	4,193,315	4,968,820	5,667,556	6,367,165	7,155,101	7,870,611	9,194,182	10,740,332
Per capita income (dollars)	18,259	19,875	21,227	22,499	23,850	25,014	27,036	29,221

Source: Census 1993m; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a.

Table L.1–74. Los Alamos National Laboratory Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	18,800	20,500	21,900	23,200	24,500	25,800	27,900	30,200
Rio Arriba County	36,900	40,200	42,900	45,500	48,000	50,600	54,700	59,100
Espanola	10,000	10,800	11,600	12,300	12,900	13,700	14,800	15,900
Santa Fe County	114,200	124,300	132,700	140,700	148,300	156,400	169,000	182,700
Santa Fe	63,600	69,200	73,900	78,400	82,600	87,100	94,200	101,800
ROI Total	169,900	185,000	197,500	209,400	220,800	232,800	251,600	272,000

Note: City values are included within county totals.

Source: Census 1993m; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–75. Los Alamos National Laboratory Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	7,900	8,600	9,100	9,700	10,200	10,800	11,600	12,600
Rio Arriba County	15,400	16,800	17,900	19,000	20,000	21,100	22,800	24,700
Espanola	4,000	4,400	4,700	5,000	5,200	5,500	6,000	6,400
Santa Fe County	47,800	52,100	55,600	59,000	62,200	65,600	70,900	76,600
Santa Fe	28,100	30,600	32,700	34,600	36,500	38,500	41,600	45,000
ROI Total	71,100	77,500	82,600	87,700	92,400	97,500	105,300	113,900

Note: City values are included within county totals.
Source: Census 1991h; Table L.1–74.

Table L.1–76. Los Alamos National Laboratory Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	3,750	4,090	4,360	4,630	4,880	5,140	5,560	6,010
Los Alamos Public Schools	3,750	4,090	4,360	4,630	4,880	5,140	5,560	6,010
Rio Arriba County	7,280	7,920	8,470	8,980	9,460	9,970	10,790	11,660
Chama Valley Ind. School District #1	600	650	700	740	780	820	890	960
Dulce Ind. School District #21	730	790	850	900	950	1,000	1,080	1,170
Espanola Public School District	5,470	5,950	6,360	6,740	7,100	7,490	8,100	8,750
Jemez Mt. School District #53	480	530	560	600	630	660	720	780
Santa Fe County	15,280	16,640	17,770	18,830	19,860	20,940	22,630	24,460
Pojoaque Valley School District #1	1,890	2,060	2,200	2,330	2,460	2,590	2,800	3,030
Santa Fe Public School District	13,390	14,580	15,570	16,500	17,400	18,350	19,830	21,430
ROI Total	26,310	28,650	30,600	32,440	34,200	36,050	38,980	42,130

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–74.

Table L.1–77. Los Alamos National Laboratory Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	255	278	297	315	332	350	378	409
Los Alamos Public Schools	255	278	297	315	332	350	378	409
Rio Arriba County	402	436	466	494	521	550	596	643
Chama Valley Ind. School District #1	42	45	48	51	54	57	62	67
Dulce Ind. School District #21	42	45	48	51	54	57	62	67
Espanola Public School District	289	314	336	356	375	396	428	462
Jemez Mt. School District #53	29	32	34	36	38	40	44	47
Santa Fe County	861	937	1,002	1,061	1,119	1,180	1,275	1,379
Pojoaque Valley School District #1	109	118	127	134	141	149	161	174
Santa Fe Public School District	753	819	875	927	978	1,031	1,114	1,205
ROI Total	1,518	1,651	1,765	1,870	1,972	2,080	2,249	2,431

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–74.

Table L.1–78. Los Alamos National Laboratory Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	42	45	48	51	54	57	62	67
Rio Arriba County	27	30	32	34	36	38	41	44
Espanola	24	27	28	30	32	33	36	39
Santa Fe County	68	74	79	84	89	93	101	109
Santa Fe	106	115	123	130	137	145	157	169
ROI Total	267	291	310	329	348	366	397	428

Source: Socio 1996a; Table L.1–74.

Table L.1–79. Los Alamos National Laboratory Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	136	148	158	168	177	186	201	218
Rio Arriba County	276	300	321	340	359	378	409	442
Espanola	24	26	28	30	31	33	36	38
Santa Fe County	257	280	299	317	334	352	381	411
Santa Fe	107	116	124	132	139	147	158	171
ROI Total	800	870	930	987	1,040	1,096	1,185	1,280

Source: Socio 1996a; Table L.1–74.

Table L.1–80. Los Alamos National Laboratory Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
Los Alamos County	29	32	34	36	38	40	44	47
Rio Arriba County	33	36	38	41	43	45	49	53
Santa Fe County	NA	NA	NA	NA	NA	NA	NA	NA
ROI Total	32	35	37	40	42	44	47	51

Note: NA=not available. Some hospitals in Santa Fe County are unable to provide occupancy data.
Source: AHA 1995a; Table L.1–74.

Table L.1–81. Los Alamos National Laboratory Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
Los Alamos County	46	50	53	56	59	63	68	73
Rio Arriba County	22	24	26	28	29	31	33	36
Santa Fe County	248	270	289	306	322	340	367	397
ROI Total	316	344	368	390	410	434	468	506

Source: AMA 1995a; Table L.1–74.

Table L.1–82. Representative Site for the Partially Completed Reactor Facility Regional Economic Area Employment and Economy, 1995-2040

Regional Economic Area	1995	2000	2005	2010	2015	2020	2030	2040
Civilian labor force	471,400	490,900	508,000	526,500	547,100	568,500	607,700	649,600
Total employment	442,500	460,800	476,800	494,200	513,500	533,600	570,400	609,700
Unemployment rate (percent)	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
Total personal income (thousands of dollars)	17,003,392	18,438,982	19,741,968	21,210,463	22,899,239	24,725,301	28,251,496	32,280,578
Per capita income (dollars)	18,086	18,835	19,489	20,200	20,989	21,810	23,313	24,920

Source: BW 1995b:1; Census 1993b; Census 1993p; Census 1995a; DOC 1994j; DOC 1995a; DOC 1996a; DOC 1996b; DOL 1991a; DOL 1995a; NFS 1995b:2; OR LMES 1995e.

Table L.1–83. Representative Site for the Partially Completed Reactor Facility Region of Influence Population, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	58,000	60,400	62,400	64,700	67,300	69,900	74,700	79,900
County B	50,000	52,000	53,800	55,800	58,000	60,200	64,400	68,800
County C	260,100	270,900	280,300	290,500	301,900	313,7000	335,300	358,400
City #1	159,200	155,900	159,100	165,000	171,700	178,700	191,400	204,900
City #2	20,400	21,300	22,000	22,800	23,700	24,600	26,300	28,100
ROI Total	368,100	383,300	396,500	411,000	427,200	443,800	474,400	507,100

Note: City values are included within county totals.

Source: Census 1993p; Census 1995a; DOC 1994j; DOC 1996a; DOC 1996b.

Table L.1–84. Representative Site for the Partially Completed Reactor Region of Influence Total Number of Owner and Renter Housing Units, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	23,000	23,900	24,700	25,600	26,700	27,700	29,600	31,600
County B	19,400	20,300	21,000	21,700	22,600	23,500	25,100	26,800
County C	104,400	108,700	112,500	116,600	121,200	125,900	134,600	143,900
City #1	66,500	65,200	66,500	69,000	71,800	74,700	80,000	85,700
City #2	8,800	9,200	9,500	9,900	10,300	10,700	11,400	12,200
ROI Total	146,800	152,900	158,200	163,900	170,500	177,100	189,300	202,300

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Census 1991p; Table L.1–83.

Table L.1–85. Representative Site for the Partially Completed Reactor Region of Influence Total Student Enrollment, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	9,890	10,300	10,660	11,050	11,480	11,930	12,760	13,630
School district #1	7,250	7,550	7,810	8,100	8,410	8,740	9,350	9,990
School district #2	2,640	2,750	2,850	2,950	3,070	3,190	3,410	3,640
County B	9,280	9,660	10,000	10,370	10,770	11,190	11,960	12,790
School district #1	6,430	6,690	6,930	7,180	7,460	7,750	8,280	8,860
School district #2	2,850	2,970	3,070	3,190	3,310	3,440	3,680	3,930
County C	41,920	43,660	45,170	46,830	48,650	50,550	54,040	57,760
School district #1	17,330	18,050	18,670	19,360	20,110	20,900	22,340	23,880
School district #2	24,590	25,610	26,500	27,470	28,540	29,650	31,700	33,880
ROI Total	61,090	63,620	65,830	68,250	70,900	73,670	78,760	84,180

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–83.

Table L.1–86. Representative Site for the Partially Completed Reactor Region of Influence Total Number of Teachers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	640	667	690	715	743	772	825	882
School district #1	479	499	516	535	556	577	617	660
School district #2	161	168	174	180	187	195	208	222
County B	609	634	656	680	706	734	785	839
School district #1	399	416	430	446	463	481	515	550
School district #2	210	218	226	234	243	253	270	289
County C	2,693	2,805	2,902	3,008	3,125	3,247	3,471	3,710
School district #1	1,063	1,107	1,145	1,187	1,233	1,281	1,370	1,464
School district #2	1,630	1,698	1,757	1,821	1,892	1,966	2,101	2,246
ROI Total	3,942	4,106	4,248	4,403	4,574	4,753	5,081	5,431

Note: Bolded areas are county totals and unbolded areas are school districts.
Source: Socio 1996a; Table L.1–83.

Table L.1–87. Representative Site for the Partially Completed Reactor Region of Influence Total Number of Sworn Police Officers, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	51	54	55	57	60	62	66	71
County B	33	35	36	37	39	40	43	46
County C	102	119	126	130	135	140	149	159
City #1	328	321	327	340	353	368	394	422
City #2	34	36	37	38	40	41	44	47
ROI Total	548	565	581	602	627	651	696	745

Source: DOJ 1995a; Table L.1–83.

Table L.1–88. Representative Site for the Partially Completed Reactor Region of Influence Total Number of Firefighters, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	395	411	426	441	458	476	509	544
County B	465	484	501	519	540	561	599	641
County C	425	494	524	542	562	583	621	661
City #1	175	171	175	181	189	196	210	225
City #2	30	31	32	34	35	36	39	41
ROI Total	1,490	1,591	1,658	1,717	1,784	1,852	1,978	2,112

Source: Socio 1996a; Table L.1–83.

Table L.1–89. Representative Site for the Partially Completed Reactor Region of Influence Hospital Occupancy Rates, 1995-2040

County/City	1995 (percent)	2000 (percent)	2005 (percent)	2010 (percent)	2015 (percent)	2020 (percent)	2030 (percent)	2040 (percent)
County A	47	49	51	52	55	57	61	65
County B	71	73	76	79	82	85	91	97
County C	59	61	64	66	68	71	76	81
ROI Average	59	62	64	66	69	72	77	82

Source: AHA 1995a; Table L.1–83.

Table L.1–90. Representative Site for the Partially Completed Reactor Region of Influence Total Number of Doctors, 1995-2040

County/City	1995	2000	2005	2010	2015	2020	2030	2040
County A	30	31	33	34	35	36	39	42
County B	33	35	36	37	39	40	43	46
County C	466	485	502	520	541	562	600	642
ROI Total	529	551	571	591	615	638	682	730

Source: AMA 1995a; Table L.1–83.

Appendix M
Health and Safety

M.1 INTRODUCTION

This appendix presents detailed information on the potential impacts and risks to humans associated with releases of radioactivity and hazardous chemicals from the proposed storage and disposition technologies during normal operations and from postulated accidents. This information is intended to support the public and occupational health and safety assessments described in Sections 4.2 and 4.3 of this programmatic environmental impact statement (PEIS). Section M.2 provides information on normal radiological impacts, Section M.3 provides information on normal hazardous chemical impacts, Section M.4 provides information on human health and epidemiologic studies, and Section M.5 provides information on postulated facility accidents.

M.2 RADIOLOGICAL IMPACTS TO HUMAN HEALTH DURING NORMAL OPERATIONS

This section presents supporting information on the potential radiological impacts of normal operation to humans. This section provides the reader with background information on the nature of radiation (Section M.2.1), the methodology used to calculate radiological impacts (Section M.2.2), radiological releases from fissile material storage and disposition facilities (Section M.2.3), and radiological impacts from various fissile material storage and disposition facilities at each site (Sections M.2.4 through M.2.15).

A further description of the methodology used to assess the normal radiological impacts presented in this appendix and a detailed listing of the data used in the assessments are given in *Health Risk Data for Storage and Disposition of Weapons-Usable Fissile Materials* (Health Risk Data, October 1996).

M.2.1 BACKGROUND

M.2.1.1 Nature of Radiation and Its Effects on Humans

What is Radiation? Humans are constantly exposed to radiation from the solar system and from the earth's rocks and soil. This radiation contributes to the natural background radiation x ray that has always been around us. But there are also manmade sources of radiation, such as medical and dental x rays, household smoke detectors, and materials released from nuclear and coal-fired powerplants.

All matter in the universe is composed of atoms, and radiation comes from the activity of these tiny particles. Atoms are made up of even smaller particles (protons, neutrons, electrons). The number and arrangement of these particles distinguishes one atom from another.

Atoms of different types are known as elements. There are over 100 natural and manmade elements. Some of these elements, such as uranium (U), radium, plutonium (Pu), and thorium, share a very important quality: they are unstable. As they change into more stable forms, invisible waves of energy or particles, known as ionizing radiation, are released. Radioactivity is the emitting of this radiation.

Ionizing radiation refers to the fact that this energy force can ionize, or electrically charge atoms by stripping off electrons. Ionizing radiation can cause a change in the chemical composition of many things, including living tissue (organs), which can affect the way they function.

The effects on people of radiation that is emitted during disintegration (decay) of a radioactive substance depends on the kind of radiation (alpha and beta particles, and gamma and x rays) and the total amount of

radiation energy absorbed by the body. The total energy absorbed per unit quantity of tissue is referred to as absorbed dose. The absorbed dose, when multiplied by certain quality factors and factors that take into account different sensitivities of various tissues, is referred to as effective dose equivalent, or where the context is clear, simply dose. The common unit of effective dose equivalent is the roentgen equivalent man (rem) (1 rem equals 1,000 millirem [mrem]).

Alpha particles are the heaviest of these direct types of ionizing radiation, and despite a speed of about 16,000 kilometers (km)/second (s) (9,940 miles [mi]/s), they can travel only several centimeters in air. Alpha particles lose their energy almost as soon as they collide with anything. They can easily be stopped by a sheet of paper or the skin's surface.

Beta particles are much lighter than alpha particles. They can travel as much as 160,000 km/s (99,400 mi/s) and can travel in the air for a distance of about 3 meters (m) (9.8 feet [ft]). Beta particles can pass through a sheet of paper, but may be stopped by a thin sheet of aluminum foil or glass.

Gamma and x rays, unlike alpha or beta particles, are waves of pure energy. Gamma rays travel at the speed of light (300,000 km/s [186,000 mi/s]). Gamma radiation is very penetrating and requires a thick wall of concrete, lead, or steel to stop it.

The neutron is another particle which contributes to radiation exposure, both directly and indirectly. The latter is associated with the gamma rays and alpha particles which are emitted following neutron capture in matter. A neutron has about one quarter the weight of an alpha particle and can travel at speeds of up to 39,000 km/s (24,200 mi/s). Neutrons are more penetrating than beta particles, but less than gamma rays.

The radioactivity of a material decreases with time. The time it takes a material to lose half of its original radioactivity is its half-life. For example, a quantity of iodine-131, a material that has a half-life of 8 days, will lose one-half of its radioactivity in that amount of time. In 8 more days, one-half of the remaining radioactivity will be lost, and so on. Eventually, the radioactivity will essentially disappear. Each radioactive element has a characteristic half-life. The half-lives of various radioactive elements may vary from millionths of a second to millions of years.

As a radioactive element gives up its radioactivity, it often changes to an entirely different element, one that may or may not be radioactive. Eventually, a stable element is formed. This transformation may take place in several steps and is known as a decay chain. Radium, for example, is a naturally occurring radioactive element with a half-life of 1,622 years. It emits an alpha particle and becomes radon, a radioactive gas with a half-life of only 3.8 days. Radon decays to polonium and through a series of steps to bismuth and ultimately to lead.

Units of Radiation Measure. Scientists and engineers use a variety of units to measure radiation. These different units can be used to determine the amount, type and intensity of radiation. Just as heat can be measured in terms of its intensity or its effects using units of calories or degrees, amount of radiation can be measured in curies (Ci), radiation absorbed doses (rads), or rems.

The curie, named after the French scientists Marie and Pierre Curie, describes the "intensity" of a sample of radioactive material. The rate of decay of 1 gram of radium is the basis of this unit of measure. It is equal to 3.7×10^{10} disintegrations (decays)/s.

The total energy absorbed per unit quantity of tissue is referred to as absorbed dose. The rad is the unit of measurement for the physical absorption of radiation. Much like sunlight heats the pavement by giving up an amount of energy to it, radiation gives up rads of energy to objects in its path. One rad is equal to the amount of radiation that leads to the deposition of 0.01 joule of energy per kilogram of absorbing material.

A rem is a measurement of the dose from radiation based on its biological effects. The rem is used to measure the effects of radiation on the body, much like degrees Centigrade can be used to measure the effects of sunlight heating pavement. Thus, 1 rem of one type of radiation is presumed to have the same biological effects as 1 rem of any other kind of radiation. This standard allows comparison of the biological effects of radionuclides that emit different types of radiation.

An individual may be exposed to ionizing radiation externally from a radioactive source outside the body, and/or internally from ingesting radioactive material. The external dose is different from the internal dose. An external dose is delivered only during the actual time of exposure to the external radiation source. An internal dose, however, continues to be delivered as long as the radioactive source is in the body, although both radioactive decay and elimination of the radionuclide by ordinary metabolic processes decrease the dose rate with the passage of time. The dose from internal exposure is calculated over 50 years following the initial exposure.

The three types of doses calculated in this include an external dose, an internal dose, and a combined external and internal dose. Each type of dose is discussed separately below.

External Dose. The external dose can arise from several different pathways. All these pathways have in common the fact that the radiation causing the exposure is external to the body. In this PEIS, these pathways include exposure to a cloud of radiation passing overhead of the receptor, standing on ground which is contaminated with radioactivity, swimming in contaminated water, and boating in contaminated water. The appropriate measure of dose is called the effective dose equivalent. It should be noted that if the receptor departs from the source of radiation exposure, his dose rate will be reduced. It is assumed that external exposure occurs uniformly during the year.

Internal Dose. The internal dose arises from a radiation source entering the human body through either ingestion of contaminated food and water or inhalation of contaminated air. In this PEIS, pathways for internal exposure include ingestion of crops contaminated either by airborne radiation depositing on the crops or by irrigation of crops using contaminated water sources, ingestion of animal products from animals that ingested contaminated food, ingestion of contaminated water, inhalation of contaminated air, and absorption of contaminated water through the skin during swimming. Unlike external exposures, once the radiation enters the body, it remains there for various periods of time that depend on decay and biological elimination rates. The unit of measure for internal doses is the committed dose equivalent. It is the internal dose that each body organ receives from 1 "year intake" (ingestion plus inhalation). Normally, a 50- or 70-year dose-commitment period is used (i.e., the 1 year intake period plus 49 or 69 years). The dose rate increases during the 1 year of intake. The dose rate, after the 1 year of intake, slowly declines as the radioactivity in the body continues to produce a dose. The integral of the dose rate over the 50 or 70 years gives the committed dose equivalent. In this PEIS, a 50-year, dose-commitment period was used.

The various organs of the body have different susceptibilities to harm from radiation. The quantity that takes these different susceptibilities into account to provide a broad indicator of the risk to the health of an individual from radiation is called the committed effective dose equivalent. It is obtained by multiplying the committed dose equivalent in each major organ or tissue by a weighting factor associated with the risk susceptibility of the tissue or organ, then summing the totals. It is possible that the committed dose equivalent to an organ is larger than the committed effective dose equivalent if that organ has a small weighting factor. The concept of committed effective dose equivalent applies only to internal pathways.

Combined External and Internal Dose. For convenience, the sum of the committed effective dose equivalent from internal pathways and the effective dose equivalent from external pathways is also called the committed effective dose equivalent in this PEIS (note that in Department of Energy [DOE] Order 5400.1, this quantity is called the effective dose equivalent).

The units used in this PEIS for committed dose equivalent, effective dose equivalent, and committed effective dose equivalent to an individual are the rem and mrem (1/1000 of 1 rem). The corresponding unit for the collective dose to a population (the sum of the doses to members of the population, or the product of the number of exposed individuals and their average dose) is the person-rem.

Sources of Radiation. The average American receives a total of about 350 mrem/year (yr) from all sources of radiation, both natural and manmade. The sources of radiation can be divided into six different categories: cosmic radiation, terrestrial radiation, internal radiation, consumer products, medical diagnosis and therapy, and other sources (NCRP 1987a:9-15). Each category is discussed below.

Cosmic radiation is ionizing radiation resulting from energetic charged particles from space continuously hitting the earth's atmosphere. These particles and the secondary particles and photons they create are cosmic radiation. Because the atmosphere provides some shielding against cosmic radiation, the intensity of this radiation increases with altitude above sea level. For the sites considered in this PEIS, the cosmic radiation ranged from 27 to 50 mrem/yr. The average dose to the people in the United States is about 27 mrem/yr.

External terrestrial radiation is the radiation emitted from the radioactive materials in the earth's rocks and soils. The average dose from external terrestrial radiation is about 28 mrem/yr. The external terrestrial radiation for the sites in this PEIS ranged from 15 to 63 mrem/yr.

Internal radiation arises from the human body metabolizing natural radioactive material which has entered the body by inhalation or ingestion. Natural radionuclides in the body include isotopes of U, thorium, radium, radon, polonium, bismuth, potassium, rubidium, and carbon. The major contributor to the annual dose equivalent for internal radioactivity are the short-lived decay products of radon which contribute about 200 mrem/yr. The average dose from other internal radionuclides is about 39 mrem/yr.

Consumer products also contain sources of ionizing radiation. In some products, like smoke detectors and airport x ray machines, the radiation source is essential to the products' operation. In other products, such as television and tobacco, the radiation occurs incidentally to the product function. The average dose is about 10 mrem/yr.

Radiation is an important diagnostic medical tool and cancer treatment. Diagnostic x rays result in an average exposure of 39 mrem/yr. Nuclear medical procedures result in an average exposure of 14 mrem/yr.

There are a few additional sources of radiation that contribute minor doses to individuals in the United States. The dose from nuclear fuel cycle facilities such as uranium mines, mills and fuel processing plants, nuclear power plants and transportation routes has been estimated to be less than 1 mrem per year. Radioactive fallout from atmospheric atomic bomb tests, emissions of radioactive material from DOE and Nuclear Regulatory Commission (NRC) licensed facilities, emissions from certain mineral extraction facilities, and transportation of radioactive materials contributes less than 1 mrem/yr to the average dose to an individual. Air travel contributes approximately 1 mrem/yr to the average dose.

The collective (or population) dose to an exposed population is calculated by summing the estimated doses received by each member of the exposed population. This total dose received by the exposed population is measured in person-rem. For example, if 1,000 people each received a dose of 1 mrem (0.001 rem), the collective dose is 1,000 persons x 0.001 rem = 1.0 person-rem. Alternatively, the same collective dose (1.0 person-rem) results from 500 people each of whom received a dose of 2 mrem (500 persons x 2 mrem = 1 person-rem).

Limits of Radiation Exposure. The amount of manmade radiation that the public may be exposed to is limited by Federal regulations. Although most scientists believe that radiation absorbed in small doses over several years is not harmful, U.S. Government regulations assume that the effects of all radiation exposures are cumulative.

Under the *Clean Air Act*, the exposure to a member of the general public from DOE facility releases into the atmosphere is limited by the Environmental Protection Agency (EPA) to a dose of 10 mrem/yr in addition to the natural background and medical radiation normally received (40 Code of Federal Regulations [CFR] 61, Subpart H). DOE also limits to 10 mrem the dose annually received from material released to the atmosphere (DOE Order 5400.5). The EPA and DOE also limit the annual dose to a member of the general public from radioactive releases to drinking water to 4 mrem, as required under the *Safe Drinking Water Act* (40 CFR 141; DOE Order 5400.5). The annual dose from all radiation sources from a site is limited by the EPA to 25 mrem (40 CFR 190). The DOE annual limit of radiation dose to a member of the general public from all DOE facilities is 100 mrem total, from all pathways (DOE Order 5400.5).

All DOE facilities covered by this PEIS operate well below this limit. It is estimated that the average individual in the United States receives a dose of about 0.3 rem (300 mrem) per year from natural sources of radiation. For perspective, a modern chest x ray results in an approximate dose of 0.006 rem (6 mrem), while a diagnostic pelvis and hip x ray results in an approximate dose of 0.065 rem (65 mrem) (NCRP 1987a:45). A person must receive an acute (short-term) dose of approximately 600 rem (600,000 mrem) before there is a high probability of near-term death (NAS 1990a:176).

For people working in an occupation that involves radiation, DOE and the NRC limit doses to 5 rem (5,000 mrem) in any 1 year (10 CFR 20; 10 CFR 835). For NRC-licensed facilities, the applicable site dose limits depend on the facility type. For other-than-power-reactors, the EPA limits discussed above apply. For power reactors, the annual total dose limit from all releases combined is the same as the EPA limit of 25 mrem (40 CFR 190). However, to demonstrate compliance with the as low as reasonably achievable philosophy, efforts must be made to further reduce releases to the guideline values given in Appendix I to 10 CFR 50.

M.2.1.2 Health Effects

Radiation exposure and its consequences are topics of interest to the general public. For this reason, this PEIS places much emphasis on the consequences of exposure to radiation, even though the effects of radiation exposure under most circumstances evaluated in this PEIS are small. This section explains the basic concepts used in the evaluation of radiation effects in order to provide the background for later discussion of impacts.

Radiation can cause a variety of ill-health effects in people. The most significant ill-health effect to depict the consequences of environmental and occupational radiation exposure is induction of cancer fatalities. This effect is referred to as "latent" cancer fatalities because the cancer may take many years to develop and for death to occur and may not actually be the cause of death. In the discussions which follow, it should be noted that all fatal cancers are latent and the term "latent" is not used.

Health impacts from radiation exposure, whether from sources external or internal to the body, generally are identified as "somatic" (affecting the individual exposed) or "genetic" (affecting descendants of the exposed individual). Radiation is more likely to produce somatic effects rather than genetic effects. Therefore, for this PEIS, only the somatic risks are presented. The somatic risks of most importance are the induction of cancers. Except for leukemia, which can have an induction period (time between exposure to carcinogen and cancer diagnosis) of as little as 2 to 7 years, most cancers have an induction period of more than 20 years.

For a uniform irradiation of the body, the incidence of cancer varies among organs and tissues; the thyroid and skin demonstrate a greater sensitivity than other organs. However, such cancers also produce relatively low mortality rates because they are relatively amenable to medical treatment. Because of the readily available data for cancer mortality rates and the relative scarcity of prospective epidemiologic studies, somatic effects leading to cancer fatalities rather than cancer incidence are presented in this PEIS. The numbers of cancer fatalities can be used to compare the risks among the various alternatives.

The fatal cancer risk estimators presented in this appendix for radiation technically apply only to low-linear energy transfer radiation (gamma rays and beta particles). However, on a per rem rather than a per rad basis, the fatal risk estimators are higher for this type of radiation than for high-linear energy transfer radiation (alpha particles). In this PEIS, the low-linear energy transfer risk estimators are conservatively assumed to apply to all radiation exposures.

The National Research Council's Committee on the Biological Effects of Ionizing Radiations (BEIR) has prepared a series of reports to advise the U.S. Government on the health consequences of radiation exposures. The latest of these reports, *Health Effects of Exposure to Low Levels of Ionizing Radiation BEIR V*, published in 1990, provides the most current estimates for excess mortality from leukemia and cancers other than leukemia expected to result from exposure to ionizing radiation. The BEIR V report updates the models and risk estimates provided in the earlier report of the BEIR III Committee, *The Effects of Populations of Exposure to Low-Levels of Ionizing Radiation,* published in 1980. The BEIR V models were developed for application to the U.S. population.

The BEIR V provides estimates that are consistently higher than those in BEIR III. This is attributed to several factors including the use of a linear dose response model for cancers other than leukemia, revised dosimetry for the Japanese atomic bomb survivors, and additional follow-up studies of the atomic bomb survivors and other cohorts. The BEIR III employs constant relative and absolute risk models, with separate coefficients for each of several sex and age-at-exposure groups, while BEIR V develops models in which the excess relative risk is expressed as a function of age at exposure, time after exposure, and sex for each of several cancer categories. The BEIR III models were based on the assumption that absolute risks are comparable between the atomic bomb survivors and the U.S. population, while BEIR V models were based on the assumption that the relative risks are comparable. For a disease such as lung cancer, where baseline risks in the United States are much larger than those in Japan, the BEIR V approach leads to larger risk estimates than the BEIR III approach.

The models and risk coefficients in BEIR V were derived through analyses of relevant epidemiologic data including the Japanese atomic bomb survivors, ankylosis spondylitis patients, Canadian and Massachusetts fluoroscopy patients (breast cancer), New York postpartum mastitis patients (breast cancer), Israel Tinea Capitis patients (thyroid cancer), and Rochester thymus patients (thyroid cancer). Models for leukemia, respiratory cancer, digestive cancer, and other cancers used only the atomic bomb survivor data, although results of analyses of the ankylosis spondylitis patients were considered. Atomic bomb survivor analyses were based on revised dosimetry with an assumed Relative Biological Effectiveness of 20 for neutrons, and were restricted to doses less than 400 rads. Estimates of risks of fatal cancers other than leukemia were obtained by totaling the estimates for breast cancer, respiratory cancer, digestive cancer and other cancers.

Risk Estimates for Doses Received During an Accident. The BEIR V includes risk estimates for a single exposure of 10 rem to a population of 100,000 people (1.0×10^6 person-rem). In this case, fatality estimates for leukemia, breast cancer, respiratory cancer, digestive cancer, and other cancers are given for both sexes and nine age-at-exposure groups. These estimates, based on the linear model, are summarized in Table M.2.1.2–1. The average risk estimate from all ages and both sexes is 885 excess cancer fatalities per million person-rem. This value has been conservatively rounded up to 1,000 excess cancer fatalities per million person-rem. Section M.5.1.3.2 contains additional discussions on accident risk estimators.

Although values for other health effects are not presented in this PEIS, the risk estimators for non-fatal cancers and for genetic disorders to future generations are estimated to be approximately 200 and 260 per million person-rem, respectively. These values are based on information presented in the *1990 Recommendations of the International Commission on Radiological Protection* (ICRP Publication 60) and are seen to be 20 percent and 26 percent, respectively, of the fatal cancer estimator. Thus, for example, if the number of excess fatal cancers is projected to be "X," the number of excess genetic disorders would be 0.26 times "X."

Risk Estimates for Doses Received During Normal Operation. For low doses and dose rates, a linear-quadratic model was found to provide a significantly better fit to the data for leukemia than a linear one, and leukemia risks were based on a linear-quadratic function. This reduces the effects by a factor of two over estimates that are obtained from the linear model. For other cancers, linear models were found to provide an adequate fit to the data, and were used for extrapolation to low doses. However, the BEIR V Committee recommended reducing these linear estimates by a factor between 2 and 10 for doses received at low dose rates. For this PEIS, a risk reduction factor of two was adopted for conservatism.

Table M.2.1.2–1. Lifetime Risks per 100,000 Persons Exposed to a Single Exposure of 10 rem

	Type of Fatal Cancer		
Gender	Leukemia[a]	Cancers Other Than Leukemia	Total Cancers
Male	220	660	880
Female	160	730	890
Average	**190**	**695**	**885**[b]

[a] These are the linear estimates, and are double the linear-quadratic estimates provided in BEIR V for leukemia at low doses and dose-rates.

[b] This value has been rounded up to 1,000 excess cancer fatalities per million person-rem.

Source: NAS 1990a.

Based on the above discussion, the resulting risk estimator would be equal to half the value observed for accident situations or approximately 500 excess fatal cancer per million person-rem (0.0005 excess fatal cancer per person-rem). This is the risk value used in this PEIS to calculate fatal cancers to the general public during normal operations. For workers, a value of 400 excess fatal cancers per million person-rem (0.0004 excess fatal cancer per person-rem) is used in this PEIS. This lower value reflects the absence of children (who are more radiosensitive than adults) in the workforce. Again, based on information provided in the *1990 Recommendations of the International Commission of Radiological Protection* (ICRP Publication 60), the health risk estimators for nonfatal cancer and genetic disorders among the public are 20 percent and 26 percent, respectively, of the fatal cancer risk estimator. For workers they are both 20 percent of the fatal cancer risk estimator. For this PEIS, only fatal cancers are presented.

The risk estimates may be applied to calculate the effects of exposing a population to radiation. For example, in a population of 100,000 people exposed only to natural background radiation (0.3 rem/yr), 15 latent cancer fatalities per year would be inferred to be caused by the radiation (100,000 persons x 0.3 rem/yr x 0.0005 latent cancer fatalities per person-rem = 15 latent cancer fatalities/yr).

Sometimes, calculations of the number of excess cancer fatalities associated with radiation exposure do not yield whole numbers and, especially in environmental applications, may yield numbers less than 1.0. For example, if a population of 100,000 were exposed as above, but to a total dose of only 0.001 rem, the collective dose would be 100 person-rem, and the corresponding estimated number of latent cancer fatalities would be 0.05 (100,000 persons x 0.001 rem x 0.0005 latent cancer fatalities/person-rem = 0.05 latent fatal cancers).

For latent cancer fatalities less than 1.0, the estimated 0.05 latent cancer fatalities is interpreted as a statistical estimate. That is, 0.05 is the *average* number of deaths that would result if the same exposure situation were applied to many different groups of 100,000 people. In most groups, no person (0 people) would incur a latent cancer fatality from the 0.001 rem dose each member would have received. In a small fraction of the groups, 1 latent fatal cancer would result; in exceptionally few groups, 2 or more latent fatal cancers would occur. The

average number of deaths over all the groups would be 0.05 latent fatal cancers (just as the average of 0, 0, 0, and 1 is 1/4, or 0.25). The most likely outcome is 0 latent cancer fatalities.

These same concepts apply to estimating the effects of radiation exposure on a single individual. Consider the effects, for example, of exposure to background radiation over a lifetime. The "number of latent cancer fatalities" corresponding to a single individual's exposure over a (presumed) 72-year lifetime to 0.3 rem/yr is the following:

1 person x 0.3 rem/year x 72 years x 0.0005 latent cancer fatalities/person-rem = 0.011 latent cancer fatalities.

Again, this should 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 might incur a latent fatal cancer caused by the exposure over his full lifetime. Presented another way, this method estimates that approximately 1.1 percent of the population might die of cancers induced by the radiation background.

M.2.2 METHODOLOGY FOR ESTIMATING RADIOLOGICAL IMPACTS OF NORMAL OPERATION

The radiological impacts of normal operation of reactors and support facilities were calculated using Version 1.485 of the GENII computer code. Site-specific and technology-specific input data were used, including location, meteorology, population, food production and consumption, and source terms. [Text deleted.] Section M.2.2.1 briefly describes GENII and outlines the approach used for normal operations. The approach used for design basis accidents is discussed in Section M.5 of this appendix.

M.2.2.1 GENII Computer Code

The GENII computer model, developed by Pacific Northwest Laboratory for DOE, is an integrated system of various computer modules which analyze environmental contamination resulting from acute or chronic releases to, or initial contamination in, air, water, or soil. The model calculates radiation doses to individuals and populations. The GENII computer model is well documented for assumptions, technical approach, methodology, and quality assurance issues (GENII—The Hanford Environmental Radiation Dosimetry Software System, December 1988). The GENII computer model has gone through extensive quality assurance and quality control steps. These include the comparison of results from model computations against those from hand calculations, and the performance of internal and external peer reviews. Recommendations given in these reports were incorporated into the final GENII computer model, as deemed appropriate.

For this PEIS only the ENVIN, ENV, and DOSE computer modules were used. The codes are connected through data transfer files. The output of one code is stored in a file that can be used by the next code in the system. In addition, a computer code called CREGENII was prepared to aid and assist the user with the preparation of input files into GENII.

CREGENII. The CREGENII code helps the user, through a series of interactive menus and questions, to prepare a text input file for the environmental dosimetry programs. In addition, CREGENII prepares a batch processing file to manage the file handling needed to control the operations of subsequent codes and to prepare an output report.

ENVIN. The ENVIN module of the GENII code controls the reading of the input files prepared by CREGENII and organizes the input for optimal use in the environmental transport and exposure module, ENV. The ENVIN code interprets the basic input, reads the basic GENII data libraries and other optional input files, and organizes the input into sequential segments on the basis of radionuclide decay chains.

A standardized file that contains scenario, control, and inventory parameters is used as input to ENVIN. Radionuclide inventories can be entered as functions of releases to air or water, concentrations in basic environmental media (air, soil, or water), or concentrations in foods. If certain atmospheric dispersion options have been selected, this module can generate tables of atmospheric dispersion parameters that will be used in later calculations. If the finite plume air submersion option is requested in addition to the atmospheric dispersion calculations, preliminary energy-dependent finite plume dose factors also are prepared. The ENVIN module prepares the data transfer files that are used as input by the ENV module; ENVIN generates the first portion of the calculation documentation—the run input parameters report.

ENV. The ENV module calculates the environmental transfer, uptake, and human exposure to radionuclides that result from the chosen scenario for the user specified source term. The code reads the input files from ENVIN and then, for each radionuclide chain, sequentially performs the precalculations to establish the conditions at the start of the exposure scenario. Environmental concentrations of radionuclides are established at the beginning of the scenario by assuming decay of preexisting sources, considering biotic transport of existing subsurface contamination, and defining soil contamination from continuing atmospheric or irrigation depositions. Then, for each year of postulated exposure, the code estimates air, surface soil, deep soil, groundwater, and surface water concentrations of each radionuclide in the chain. Human exposures and intakes of each radionuclide are calculated for: 1) pathways of external exposure from finite atmospheric plumes; 2) inhalation; 3) external exposure from contaminated soil, sediments, and water; 4) external exposure from special geometries; and 5) internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil. The intermediate information on annual media concentrations and intake rates are written to data transfer files. Although these may be accessed directly, they are usually used as input to the DOSE module of GENII.

DOSE. The DOSE module reads the annual intake and exposure rates defined by the ENV module and converts the data to radiation dose. External dose is calculated with precalculated factors from the EXTDF module or from a data file prepared outside of GENII. Internal dose is calculated with precalculated factors from the INTDF module.

EXTDF. The EXTDF module calculates the external dose-rate factors for submersion in an infinite cloud of radioactive materials, immersion in contaminated water, and direct exposure to plane or slab sources of radionuclides. EXTDF was not used. Instead, the dose rate factors listed in *External Dose Rate Factors for Calculation of Dose to the Public* (DOE/EH-0070) were used for this PEIS.

INTDF. Using the *Limits for Intakes of Radionuclides by Workers* (ICRP Publication 30) model, the INTDF module calculates the internal (inhalation and ingestion) dose conversion factors of radionuclides for specific organs. The factors generated by INTDF were used for the calculations presented in this PEIS.

GENII is a general purpose computer code used to model dispersion, transport, and long-term exposure effects of specific radionuclides and pathways. Sophisticated codes such as UFOTRI and ETMOD (Environmental Tritium Model) are used exclusively for modelling tritium transport and dosimetry. The UFOTRI and ETMOD codes were not chosen for use in this PEIS due to the lack of information on detailed facility design and on the breakdown of tritium into elemental and tritiated water forms, and because these codes cannot be used for modeling the exposure effects of radionuclides other than tritium. GENII was chosen because it can model both air and surface transport pathways and is not restricted to any radionuclides.

M.2.2.2 Data and Assumptions

In order to perform the dose assessments for this PEIS, different types of data must be collected and/or generated. In addition, calculational assumptions have to be made. This section discusses the data collected and/or generated for use in the dose assessment and assumptions made for this PEIS.

Meteorological Data. The meteorological data used for all sites were in the form of joint frequency data files. A joint frequency data file is a table listing the fractions of time the wind blows in a certain direction, at a certain speed, and within a certain stability class. The joint frequency data files were based on measurements over a 1-year period at various locations and at different heights at the sites. Average meteorological conditions (averaged over the 1-year period) were used for normal operation. Meteorological data are presented in Health Risk Data, October 1996.

Population Data. Population distributions were based on *1990 Census of Population and Housing* data. Projections were determined for 2030 (approximate midlife of operations) for areas within 80 km (50 mi) of the proposed facilities at each candidate site. The site population in 2030 was assumed to be representative of the population over the operational period evaluated, and was used in the impact assessments. The population was spatially distributed on a circular grid with 16 directions and 10 radial distances up to 80 kilometers. The grid was centered on the facility from which the radionuclides were assumed to be released. Population data are presented in Health Risk Data, October 1996.

Source Term Data. The source terms (quantities of radionuclides released to the environment over a given period) were estimated on the basis of latest conceptual designs of facilities and experience with similar facilities. The source terms used to generate the estimated impacts of normal operation are provided in Section M.2.3 for the storage and disposition facilities which could be located at the various sites. Source terms for candidate and representative sites are presented in Sections M.2.4 through M.2.15.

Food Production and Consumption Data. Data from the *1987 Census of Agriculture* was used to generate site-specific data for food production. Food production was spatially distributed on the same circular grid as was used for the population distributions. The consumption rates were those used in GENII for the maximum individual and average individual. People living within the 80 km (50 mi) assessment area were assumed to consume only food grown in that area.

Calculational Assumptions. Dose assessments were performed for members of the general public and workers. Dose assessments for members of the public were performed for two different types of receptors considered in this PEIS: a maximally exposed offsite individual and the general population living within 80 km (50 mi) of the facility. It was assumed that the maximally exposed individual (MEI) was located at a position on the site boundary that would yield the highest impacts during normal operation of a given alternative. If more than one facility was assumed to be operating at a site, the dose to a "maximum receptor" (that is, a potential site MEI) from each facility was calculated. This was accomplished by preliminarily designating each potential MEI as a maximum receptor for each facility modeled—subsequently, whichever maximum receptor was found to incur the largest dose was then ultimately selected as the MEI for the site. An 80-km (50-mi) population dose was calculated for each operating facility at a site. These doses were then added to give the total population dose at that site.

To estimate the radiological impacts from normal operation of reactors and support facilities, additional assumptions and factors were considered in using GENII, as follows:

- No prior deposition of radionuclides on ground surfaces was assumed.
- For the maximally exposed off-site individual, the annual exposure time to the plume and to soil contamination was 0.7 year (NRC 1977b:1.109-68).
- For the population, the annual exposure time to the plume and to soil contamination was 0.5 year (NRC 1977b:1.109-68).
- The exposed individual or population was assumed to have the characteristics and habits (for example; inhalation and ingestion rates) of the adult human.

- A semi-infinite/finite plume model was used for air immersion doses. Other pathways evaluated were ground exposure, inhalation, ingestion of food crops and animal products contaminated by either deposition of radioactivity from the air or irrigation, ingestion of fish and other aquatic food raised in contaminated water, swimming and boating in contaminated surface water, and drinking contaminated water. It should be noted that not all pathways were available at every site.

- For atmospheric releases it was assumed that ground level releases would occur for all storage and disposal facilities. For site dependent facilities, reported release heights were used and assumed to be the effective stack height. Use of the effective stack height negates plume rise thereby making the resultant doses conservative.

- The calculated doses were 50-year committed doses from 1 year of intake.

The exposure, uptake, and usage parameters used in the GENII model are provided in Tables M.2.2.2–1 through M.2.2.2–4.

Annual average doses to workers for No Action at the Hanford Site (Hanford), Nevada Test Site (NTS), Idaho National Engineering Laboratory (INEL), Pantex Plant (Pantex), Rocky Flats Environmental Technology Site (RFETS), and Los Alamos National Laboratory (LANL) were generally based on measured values received by radiation workers during the 1989 to 1992 time period. The dose values are given in a series of documents that cover this time period. Dose values for 1992 are contained in "Compilation of Doses to Workers at DOE Facilities in 1992" (DOE 1993n:7). The same type reports are used for the earlier years. The average dose received by a worker at these sites in 2005 was assumed to remain the same as the annual average during the 1989 to 1992 period. The total workforce dose in 2005 was calculated by multiplying the average worker dose by the projected number of workers in 2005. For Oak Ridge Reservation (ORR) and Savannah River Site (SRS), worker dose projections provided by the sites were used. For NRC-licensed sites, No Action worker doses were based on reported values for 1993 given in *Occupational Radiation Exposure at Commercial Nuclear Power Reactors and Other Facilities, 1993* (NUREG-0713-V15).

Doses to workers directly associated with storage and disposition facilities were taken from the reports prepared by Fluor Daniel, Inc.; Sandia National Laboratories (SNL), New Mexico; LANL; Lawrence Livermore National Laboratory (LLNL); and SRS. To obtain the total workforce dose at a site with a particular storage or disposition facility in operation, the site dose from No Action was added to that from the storage or disposition facility being evaluated. The average dose to a site worker was then calculated by dividing this dose by the total number of radiation workers at the site.

All doses to workers include a component associated with the intake of radioactivity into the body and another component resulting from external exposure to direct radiation.

A more detailed discussion of doses to workers associated with storage and disposition is given in Section M.2.3.2.

M.2.2.3 Health Effects Calculations

In this PEIS, the collective combined effective dose equivalent is the sum of the collective committed effective dose equivalent (internal dose) and the collective effective dose equivalent (external dose), as explained in Section M.2.1.1. Doses calculated by GENII were used to estimate health effects using the risk estimators presented in Section M.2.1.2. The incremental cancer fatalities in the general population and groups of workers due to radiation exposure were therefore estimated by multiplying the collective combined effective dose equivalent by 0.0005 and 0.0004 fatal cancers/person-rem, respectively.Although health risk factors are statistical factors and therefore not strictly applicable to individuals, they have been used in the past to estimate the incremental risk to an individual from exposure to radiation. Therefore, the factor of 0.0005 and 0.0004

per rem of individual committed effective dose equivalent for a member of the public and for a worker, respectively, have also been used in this PEIS to calculate the individual's incremental fatal cancer risk from exposure to radiation.

For the public, the health effects expressed in this PEIS are the risk of fatal cancers to the maximally exposed individual and the number of fatal cancers to the 80-km (50-mi) population from exposure to radioactivity released from any site over the full operational period. For workers, the health effects expressed are the risk to the average worker at a site and the number of fatal cancers to all workers at that site over the full period of site operations.

M.2.3 STORAGE AND DISPOSITION FACILITIES INFORMATION

This section presents compilations of radiological releases to the environment from facilities associated with all alternatives assessed in this PEIS except No Action. The No Action releases are presented as part of the specific site discussions in Section M.2.4 through M.2.9. This section also presents the in-plant worker doses associated with these same facilities.

M.2.3.1 Radiological Releases to the Environment

Long-Term Storage. The annual release of radioactivity to the environment associated with the alternatives for the long-term storage of Pu and highly enriched uranium (HEU) are given in Table M.2.3.1–1. The releases, by radionuclide, are given for operation of upgraded Pu storage facilities at Hanford, INEL, Pantex, and SRS and upgraded HEU storage facilities at ORR; for operation of consolidated Pu storage facilities at Hanford, NTS, INEL, Pantex, and SRS; and for operation of collocated Pu and HEU storage facilities at Hanford, NTS, INEL, Pantex, ORR, and SRS.

Front-End Processes Common to Multiple Plutonium Disposition Alternatives. The annual releases of radioactivity to the environment associated with front-end processes common to multiple Pu disposition alternatives are given in Table M.2.3.1–2. The releases, by radionuclide, include those for operation of a pit disassembly/conversion facility, a Pu conversion facility, and a mixed oxide (MOX) fuel fabrication facility. These releases are independent of site location.

Table M.2.3.1–1. Annual Radioactive Releases During Normal Operation of Long-Term Storage Facilities (curies)[a]

Facility/Radionuclides	Site			
Upgraded Pu Storage Facility	**Hanford**	**INEL**	**Pantex**	**SRS**
Pu-238	1.8×10^{-8}	2.5×10^{-9}	b	c
Pu-239	5.6×10^{-8}	9.2×10^{-8}	b	c
Pu-240	2.8×10^{-8}	2.4×10^{-8}	b	c
Pu-241	8.6×10^{-7}	8.6×10^{-8}	b	c
Pu-242	1.6×10^{-11}	3.6×10^{-12}	b	c
Am-241	3.5×10^{-8}	4.5×10^{-10}	b	c
Upgraded HEU Storage Facility	**ORR**[d]			
U-234	2.7×10^{-12}			
U-235	4.7×10^{-11}			
U-236	2.9×10^{-10}			
U-238	9.3×10^{-9}			
Consolidated Pu Storage Facility	**Hanford, NTS, INEL, Pantex, and SRS**			
Pu-238	1.5×10^{-8}			
Pu-239	5.4×10^{-7}			
Pu-240	1.4×10^{-7}			
Pu-241	5.1×10^{-7}			
Pu-242	2.1×10^{-11}			
Am-241	2.7×10^{-9}			

Table M.2.3.1–1. Annual Radioactive Releases During Normal Operation of Long-Term Storage Facilities (curies)[a] —Continued

Facility/Radionuclides	Site
Collocated Pu and HEU Storage Facility	**Hanford, NTS, INEL, Pantex, ORR, and SRS**
Pu-238	1.5×10^{-8}
Pu-239	5.4×10^{-7}
Pu-240	1.4×10^{-7}
Pu-241	5.1×10^{-7}
Pu-242	2.1×10^{-11}
Am-241	2.7×10^{-9}
U-234	2.7×10^{-12}
U-235	4.7×10^{-11}
U-236	2.9×10^{-10}
U-238	9.3×10^{-9}

[a] All releases are to the atmosphere.

[b] Radiation dose for the storage facility is calculated to be 1.8×10^{-8} for the MEI and 6.3×10^{-6} person-rem for the population within 80 km, but no radionuclide emissions are available (HNUS 1996a).

[c] Radiation dose for the storage facility is calculated to be 8.3×10^{-6} for the MEI and 3.5×10^{-4} person-rem for the population within 80 km, but no radionuclide emissions are available (SR DOE 1995e).

[d] Assumed uranium releases from Collocated Storage Facility would be applicable for the ORR Upgraded HEU Storage Facility.

Note: Am=Americium.

Source: DOE 1996e; DOE 1996f; HF 1995a:1; HNUS 1996a; IN DOE 1996a; PX MH 1995a; SRS 1996a:4.

Plutonium Disposition Alternatives. The annual releases of radioactivity to the environment associated with the Pu disposition alternatives are given in Table M.2.3.1–3 for facilities other than reactors, and in Tables M.2.3.1–4 and M.2.3.1–5 for reactors. The releases have been separated to facilitate data presentation since reactors release a much larger number of radionuclides than do the other facilities. Table M.2.3.1–3 presents the releases by radionuclide for operation of ceramic immobilization, vitrification, and the deep borehole complex. Tables M.2.3.1–4 and M.2.3.1–5 present the releases, by radionuclide, for operation of a large and a small evolutionary light water reactor (LWR), respectively.

M.2.3.2 Radiological Impacts to In-Plant Workers

Operation of each of the facilities whose releases were addressed in Section M.2.3.1 result in radiological doses and associated health effects to in-plant workers. The numbers of badged workers, the average and total worker doses, and the risks and numbers of fatal cancers are given in Table M.2.3.2–1 for workers involved with disposition activities. It should be noted that for several disposition facilities, the number of years for facility operation varies due to the fact that the duration of operation depends on the end use of that facility. For example, the MOX fuel fabrication facility could operate for either 17 years supplying fuel for evolutionary and partially completed U.S. reactors or 23 years supplying fuel for existing Canadian Deuterium Uranium reactors.

Based on a review of impacts to workers involved in similar operations, the radiological impacts to workers involved with storage activities assume an annual average dose of approximately 250 mrem per worker for the storage upgrade alternative (HF DOE 1996a:2-4; IN DOE 1996a:1-6; NT DOE 1996a:1-7. For the upgrade at Pantex, an average measurable dose of 116 mrem/yr to radiological workers was assumed to be applicable for the workers associated with storage operations (PX 1996e:2). The number of these involved workers, and therefore the total dose to the involved workforce, is site dependent. For consolidated and collocation storage alternatives that require new facilities, the annual average dose is estimated to be 258 mrem and 264 mrem per worker, respectively. For these storage facilities, the number of involved badged workers are independent of the site and would number 92 and 95, respectively; therefore, the total dose to the involved workforce is also site independent (DOE 1996e:1-6; DOE 1996f:1-8). The detailed results of worker doses associated with all storage facilities are presented in the storage public and occupational health sections of Chapter 4.

Table M.2.3.1–2. Annual Radioactive Releases During Normal Operation of Facilities for Plutonium Disposition Used by Multiple Alternatives (curies)[a]

Facility/Radionuclides	Releases
Pit Disassembly/Conversion Facility	
Pu-238	4.2×10^{-7}
Pu-239	4.3×10^{-5}
Pu-240	1.0×10^{-5}
Pu-241	3.2×10^{-5}
Pu-242	2.9×10^{-10}
Am-241	1.7×10^{-5}
Pu Conversion Facility	
Pu-238	2.3×10^{-6}
Pu-239	3.6×10^{-5}
Pu-240	1.2×10^{-5}
Pu-241	4.8×10^{-5}
Pu-242	3.8×10^{-9}
Am-241	2.6×10^{-7}
Mixed Oxide Fuel Fabrication Facility	
Pu-238	7.9×10^{-7}
Pu-239	2.9×10^{-5}
Pu-240	7.6×10^{-6}
Pu-241	2.7×10^{-5}
Pu-242	1.1×10^{-9}
Am-241	1.4×10^{-7}
U-232	1.3×10^{-7}
U-234	3.2×10^{-8}
U-235	6.2×10^{-10}
U-238	4.8×10^{-8}

[a] All releases are to the atmosphere.

Note: Am=Americium.

Source: HNUS 1996a; LANL 1996b; LANL 1996c; LANL 1996d.

Table M.2.3.1–3. Annual Radioactive Releases During Normal Operation of Non-Reactor Plutonium Disposition Facilities (curies)[a]

Facility/Radionuclides	Releases
Borehole Complex (Direct Disposition Alternative)	
Pu-238	1.2×10^{-11}
Pu-239	9.2×10^{-10}
Pu-240	2.4×10^{-10}
Pu-241	1.3×10^{-10}
Pu-242	3.6×10^{-14}
Am-241	2.0×10^{-10}
Ceramic Immobilization Facility (Immobilized Disposition Alternative)	
Pu-238	9.3×10^{-11}
Pu-239	7.0×10^{-9}
Pu-240	1.9×10^{-9}
Pu-241	9.7×10^{-10}
Pu-242	2.8×10^{-13}
Am-241	3.5×10^{-11}
Borehole Complex (Immobilized Disposition Alternative)	
Pu-238	1.4×10^{-11}
Pu-239	1.1×10^{-9}
Pu-240	2.8×10^{-10}
Pu-241	1.5×10^{-10}
Pu-242	4.1×10^{-14}
Am-241	3.0×10^{-10}
Vitrification Alternative	
Pu-238	3.7×10^{-8}
Pu-239	2.8×10^{-6}
Pu-240	7.5×10^{-7}
Pu-241	3.9×10^{-7}
Pu-242	1.1×10^{-10}
Am-241	1.4×10^{-8}
Cs-137	5.0×10^{-5}
Ceramic Immobilization Alternative	
Pu-238	9.3×10^{-11}
Pu-239	7.0×10^{-9}
Pu-240	1.9×10^{-9}
Pu-241	9.7×10^{-10}
Pu-242	2.8×10^{-13}
Am-241	3.5×10^{-11}
Cs-137	1.0×10^{-5}

[a] All releases are to the atmosphere.

Note: Am=Americium.

Source: HNUS 1996a; LLNL 1996a; LLNL 1996c; LLNL 1996d; LLNL 1996e; LLNL 1996h.

Table M.2.3.1–4. Annual Liquid and Atmospheric Radioactive Releases From the Large Evolutionary Light Water Reactor Using a Mixed Oxide Core (curies)

	Release				Release		
	Wet Site[a]		Dry Site[a]		Wet Site[a]		Dry Site[a]
Isotope	Atmospheric	Liquid	Atmospheric	Isotope	Atmospheric	Liquid	Atmospheric
H-3	6.8×10^{1}	6.0×10^{1}	1.3×10^{2}	Sr-92	7.8×10^{-4}	8.0×10^{-4}	1.6×10^{-3}
C-14	9.2	1.6×10^{-4}	9.2	Y-90	1.7×10^{-5}	1.2×10^{-6}	1.9×10^{-5}
Ar-41	6.8	0	6.8	Y-91	1.5×10^{-4}	6.7×10^{-5}	2.1×10^{-4}
Kr-83m	1.4×10^{-3}	0	1.4×10^{-3}	Y-92	4.5×10^{-4}	4.3×10^{-4}	8.8×10^{-4}
Kr-85m	2.3×10^{1}	0	2.3×10^{1}	Y-93	1.0×10^{-3}	8.3×10^{-4}	1.8×10^{-3}
Kr-85	4.9×10^{2}	0	4.9×10^{2}	Zr-95	1.0×10^{-3}	7.4×10^{-4}	1.8×10^{-3}
Kr-87	2.5×10^{1}	0	2.5×10^{1}	Nb-95	1.5×10^{-3}	8.8×10^{-4}	2.4×10^{-3}
Kr-88	3.7×10^{1}	0	3.7×10^{1}	Mo-99	1.4×10^{-2}	7.9×10^{-4}	1.5×10^{-2}
Kr-89	4.0×10^{2}	0	4.0×10^{2}	Tc-99m	3.0×10^{-4}	8.0×10^{-4}	1.1×10^{-3}
Kr-90	5.4×10^{-4}	0	5.4×10^{-4}	Ru-103	6.0×10^{-4}	2.2×10^{-4}	8.3×10^{-4}
Xe-131m	8.6×10^{1}	0	8.6×10^{1}	Rh-103m	1.1×10^{-4}	9.0×10^{-6}	1.2×10^{-4}
Xe-133m	1.4×10^{-1}	0	1.4×10^{-1}	Ru-106	3.2×10^{-5}	2.9×10^{-4}	3.2×10^{-4}
Xe-133	3.8×10^{3}	0	3.8×10^{3}	Rh-106	1.9×10^{-5}	1.7×10^{-4}	1.9×10^{-4}
Xe-135m	6.8×10^{2}	0	6.8×10^{2}	Ag-110m	6.5×10^{-7}	3.3×10^{-4}	3.3×10^{-4}
Xe-135	2.2×10^{3}	0	2.2×10^{3}	Sb-124	1.7×10^{-4}	3.6×10^{-4}	5.3×10^{-4}
Xe-137	8.6×10^{2}	0	8.6×10^{2}	Te-129m	1.7×10^{-4}	1.3×10^{-5}	1.8×10^{-4}
Xe-138	7.2×10^{2}	0	7.2×10^{2}	Te-131m	9.1×10^{-5}	4.1×10^{-5}	1.3×10^{-4}
Xe-139	6.8×10^{-4}	0	6.8×10^{-4}	I-131	2.9×10^{-1}	3.5×10^{-3}	2.9×10^{-1}
Na-24	4.1×10^{-3}	2.8×10^{-3}	6.9×10^{-3}	Te-132	2.0×10^{-5}	4.3×10^{-6}	2.5×10^{-5}
P-32	9.2×10^{-4}	1.8×10^{-4}	1.1×10^{-3}	I-132	2.3	2.8×10^{-3}	2.3
Cr-51	3.5×10^{-2}	7.7×10^{-3}	4.3×10^{-2}	I-133	1.6	9.5×10^{-3}	1.6
Mn-54	4.9×10^{-3}	2.6×10^{-3}	7.5×10^{-3}	I-134	3.6	1.6×10^{-3}	3.6
Mn-56	3.5×10^{-3}	3.8×10^{-3}	7.3×10^{-3}	Cs-134	8.9×10^{-5}	3.2×10^{-3}	3.3×10^{-3}
Fe-55	6.5×10^{-3}	5.8×10^{-3}	1.2×10^{-2}	I-135	2.4	7.5×10^{-3}	2.4
Co-56	0	5.2×10^{-3}	5.2×10^{-3}	Cs-136	1.2×10^{-4}	4.7×10^{-4}	5.8×10^{-4}
Co-57	0	7.2×10^{-5}	7.2×10^{-5}	Cs-137	4.2×10^{-4}	8.2×10^{-3}	8.6×10^{-3}
Co-58	2.4×10^{-3}	9.0×10^{-5}	2.5×10^{-3}	Cs-138	1.7×10^{-4}	1.9×10^{-4}	3.6×10^{-4}
Co-60	1.1×10^{-2}	9.1×10^{-3}	2.0×10^{-2}	Cs-139	8.2×10^{-5}	0	8.2×10^{-5}
Fe-59	6.5×10^{-4}	1.0×10^{-4}	7.5×10^{-4}	Ba-140	1.2×10^{-2}	6.1×10^{-4}	1.2×10^{-2}
Ni-63	6.5×10^{-6}	1.4×10^{-4}	1.5×10^{-4}	La-140	1.6×10^{-3}	1.5×10^{-4}	1.8×10^{-3}
Cu-64	1.0×10^{-2}	7.5×10^{-3}	1.8×10^{-2}	Ce-141	8.6×10^{-3}	1.2×10^{-4}	8.8×10^{-3}
Zn-65	8.1×10^{-3}	9.0×10^{-5}	8.2×10^{-3}	Ce-144	1.3×10^{-5}	1.3×10^{-3}	1.3×10^{-3}
Rb-89	4.3×10^{-5}	4.4×10^{-5}	8.7×10^{-5}	Pr-143	0	1.1×10^{-6}	1.1×10^{-6}
Sr-89	3.2×10^{-3}	6.3×10^{-5}	3.3×10^{-3}	Pr-144	1.9×10^{-5}	0	1.9×10^{-5}
Sr-90	2.8×10^{-5}	1.5×10^{-5}	4.3×10^{-5}	W-187	1.9×10^{-4}	9.5×10^{-5}	2.8×10^{-4}
Sr-91	6.5×10^{-4}	5.9×10^{-4}	1.2×10^{-3}	Np-239	5.9×10^{-3}	1.6×10^{-3}	7.5×10^{-3}

[a] A wet site is characterized by the potential for effluent material to be emitted either through airborne or liquid pathways. A dry site only exhibits the potential to emit effluent material via the airborne pathway. For a dry site, it was conservatively assumed that liquid and atmospheric effluents are released into the atmosphere.

Source: HNUS 1996a.

Table M.2.3.1–5. Annual Liquid and Atmospheric Radioactive Releases From the Small Evolutionary Light Water Reactor Using a Mixed Oxide Core (curies)

	Release				Release		
	Wet Site[a]		Dry Site[a]		Wet Site[a]		Dry Site[a]
Isotope	Atmospheric	Liquid	Atmospheric	Isotope	Atmospheric	Liquid	Atmospheric
H-3	8.4×10^{1}	7.5×10^{2}	8.4×10^{2}	Nb-95	2.1×10^{-3}	1.6×10^{-3}	3.7×10^{-3}
C-14	7.3	0	7.3	Mo-99	0	7.9×10^{-4}	7.9×10^{-4}
Ar-41	3.4×10^{1}	0	3.4×10^{1}	Tc-99m	0	4.6×10^{-4}	4.6×10^{-4}
Kr-85m	3.2×10^{1}	0	3.2×10^{1}	Ru-103	1.0×10^{-4}	1.8×10^{-3}	1.9×10^{-3}
Kr-85	1.7×10^{2}	0	1.7×10^{2}	Rh-103m	0	1.1×10^{-3}	1.1×10^{-3}
Kr-87	9.5	0	9.5	Ru-106	1.4×10^{-4}	3.9×10^{-2}	3.9×10^{-2}
Kr-88	3.4×10^{1}	0	3.4×10^{1}	Ag-110m	0	1.4×10^{-3}	1.4×10^{-3}
Xe-131m	2.0×10^{3}	0	2.0×10^{3}	Sb-124	0	4.3×10^{-4}	4.3×10^{-4}
Xe-133m	8.9×10^{1}	0	8.9×10^{1}	Sb-125	6.1×10^{-5}	0	6.1×10^{-5}
Xe-133	4.7×10^{3}	0	4.7×10^{3}	Te-129m	0	3.9×10^{-5}	3.9×10^{-5}
Xe-135m	9.8	0	9.8	Te-129	0	3.8×10^{-5}	3.8×10^{-5}
Xe-135	5.4×10^{2}	0	5.4×10^{2}	Te-131m	0	1.7×10^{-4}	1.7×10^{-4}
Xe-138	4.6	0	4.6	Te-131	0	3.0×10^{-5}	3.0×10^{-5}
Na-24	0	3.2×10^{-3}	3.2×10^{-3}	I-131	7.3×10^{-2}	3.6×10^{-2}	1.1×10^{-1}
P-32	0	1.8×10^{-4}	1.8×10^{-4}	Te-132	0	2.1×10^{-4}	2.1×10^{-4}
Cr-51	6.1×10^{-4}	5.2×10^{-3}	5.8×10^{-3}	I-132	0	2.4×10^{-3}	2.4×10^{-3}
Mn-54	4.4×10^{-4}	4.0×10^{-3}	4.4×10^{-3}	I-133	2.4×10^{-1}	2.0×10^{-2}	2.6×10^{-1}
Fe-55	0	7.4×10^{-3}	7.4×10^{-3}	I-134	0	8.6×10^{-5}	8.6×10^{-5}
Co-57	8.2×10^{-6}	0	8.2×10^{-6}	Cs-134	1.5×10^{-3}	1.8×10^{-2}	1.9×10^{-2}
Co-58	2.3×10^{-2}	8.6×10^{-3}	3.2×10^{-2}	I-135	0	1.4×10^{-2}	1.4×10^{-2}
Co-60	8.7×10^{-3}	1.4×10^{-2}	2.3×10^{-2}	Cs-136	1.1×10^{-4}	2.0×10^{-3}	2.1×10^{-3}
Fe-59	7.9×10^{-5}	2.2×10^{-3}	2.3×10^{-3}	Cs-137	3.7×10^{-3}	3.8×10^{-2}	4.2×10^{-2}
Ni-63	0	1.7×10^{-3}	1.7×10^{-3}	Ba-140	3.9×10^{-4}	2.5×10^{-3}	2.9×10^{-3}
Zn-65	0	8.0×10^{-5}	8.0×10^{-5}	La-140	0	2.6×10^{-3}	2.6×10^{-3}
Sr-89	1.7×10^{-3}	6.3×10^{-5}	1.8×10^{-3}	Ce-141	3.9×10^{-5}	2.4×10^{-4}	2.7×10^{-4}
Sr-90	6.0×10^{-4}	1.0×10^{-5}	6.1×10^{-4}	Ce-143	0	2.3×10^{-4}	2.3×10^{-4}
Sr-91	0	3.2×10^{-5}	3.2×10^{-5}	Ce-144	0	3.6×10^{-3}	3.6×10^{-3}
Y-91m	0	3.0×10^{-5}	3.0×10^{-5}	Pr-144	0	5.8×10^{-4}	5.8×10^{-4}
Y-91	0	5.7×10^{-5}	5.7×10^{-5}	W-187	0	2.2×10^{-4}	2.2×10^{-4}
Y-93	0	1.7×10^{-4}	1.7×10^{-4}	Np-239	0	1.0×10^{-4}	1.0×10^{-4}
Zr-95	8.5×10^{-4}	1.0×10^{-3}	1.9×10^{-3}				

[a] A wet site is characterized by the potential for effluent material to be emitted either through airborne or liquid pathways. A dry site only exhibits the potential to emit effluent material via the airborne pathway. For a dry site, it was conservatively assumed that liquid and atmospheric effluents are released into the atmosphere.

Source: HNUS 1996a.

Table M.2.3.2–1. Potential Radiological Impacts From Normal Operation to Involved Workers of Disposition Technology Alternatives and Common Activities

Facility	Years of Operation	Involved "Badged" Workforce	Average Worker Dose (mrem/yr)	Risk of Fatal Cancer[a]	Total Dose (person-rem/yr)	Fatal Cancers[a]
Front-End Processes (Common to Multiple Disposition Alternatives)						
Pit Disassembly and Conversion Facility [Text deleted.]	10	415	200	1.3×10^{-3}	83	0.33
Pu Conversion Facility [Text deleted.]	10	572	233	9.3×10^{-4}	133	0.53
MOX Fuel Fabrication Facility						
	17	125	250	1.7×10^{-3}	31	0.21
	23	125	250	2.3×10^{-3}	31	0.29
Plutonium Disposition Alternatives						
Direct Disposition Alternative						
Deep Borehole Complex	10	205	13	5.2×10^{-5}	2.7	0.011
Immobilized Disposition Alternative						
Ceramic Immobilization Facility	10	450	240	9.8×10^{-4}	110	0.44
Deep Borehole Complex	10	168	13	5.2×10^{-5}	2.2	8.8×10^{-3}
Vitrification Alternative	10	550	200	8.0×10^{-4}	110	0.44
Ceramic Immobilization Alternative	10	430	279	1.1×10^{-3}	120	0.48
Electrometallurgical Treatment Alternative	10	73	40	1.6×10^{-4}	2.9	0.012
Existing LWR	23	600 to 1,000	281 to 543	2.6×10^{-3} to 5.0×10^{-3}	172 to 602	1.6 to 5.5
Partially Completed LWR	23	1,050	360	3.2×10^{-3}	380	3.5
Evolutionary LWR						
Small	17	125	800	5.4×10^{-3}	100	0.68
Large	17	210	810	5.5×10^{-3}	170	1.2

[a] As the result of operations for the number of years given in the first column.

Source: LANL 1996b; LANL 1996c; LANL 1996d; LLNL 1996a; LLNL 1996b; LLNL 1996c; LLNL 1996d; LLNL 1996e; LLNL 1996g; LLNL 1996h; NRC 1995b; ORNL 1995b.

M.2.4 RADIOLOGICAL IMPACTS AT HANFORD SITE

This section presents the radiological impacts of the various storage and disposition alternatives at Hanford. Section M.2.4.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.4.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modeling, Hanford was divided into seven separate areas which would release radioactivity in 2005. All potential release points in each area were aggregated into a single release point. Table M.2.4–1 presents the characteristics of each of the release points including location, release height, minimum distance, and annual average dispersion to the site boundary in each of 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For further clarification on the definition of a "maximum receptor" refer to Section M.2.2.2. For example, the dose resulting from releases from the 100 Area, 200 West, 200 East, 300 Area, and the other storage and disposition alternatives (Washington Nuclear Power-1), has been determined for the maximum receptor from the 400 Area. Figure M.2.4–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred by the MEI) is then determined by the maximum dose to one of these maximum receptors. Table M.2.4–2 presents the distance, direction, and atmospheric dispersion from each release point to each of the maximum receptors. Annual radiological releases were assumed to remain constant during the full operational period.

Descriptions of population, food stuffs distributions, and aquatic foods for each release area are provided in a Health Risk Data report, October, 1996. The joint frequency distributions used for the dose assessment were based on measurements from the meteorological tower in the 200 East Area at the 10-m (33-ft) height during the time period of July 1, 1989 through August 30, 1990 and is contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables, and for the projected operational period in the text. Tables M.2.4–3 through M.2.4–6 include the radiological impacts to the public from both atmospheric releases and from using the surface water for No Action and the storage and disposition alternatives.

M.2.4.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, five of the six areas have radioactive releases into the atmosphere from normal operation. Table M.2.4.1–1 presents the estimated annual atmospheric radioactive releases.

Tables M.2.4–3 and M.2.4–4 include the atmospheric radiological impacts to the maximally exposed member of the public and the offsite population within 80 km (50 mi), respectively. The MEI would receive an annual dose of 4.4×10^{-3} mrem. An estimated fatal cancer risk of 1.1×10^{-7} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 0.46 person-rem in 2030 (midlife of operation). An estimated 0.012 fatal cancers could result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. For No Action, some areas may have radioactive releases to the offsite surface water from normal operation. Table M.2.4.1–2 presents the estimated annual liquid radioactive releases.

Tables M.2.4–5 and M.2.4–6, respectively, include the radiological impacts to the MEI and the offsite populations using surface water within 80 km (50 mi) downstream of Hanford. The maximally exposed member of the public would receive an annual dose of 9.5×10^{-4} mrem. An estimated fatal cancer risk of

Table M.2.4–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Hanford Site Boundary

Release Point[a]	100 Area	200 West	200 East	300 Area	400 Area	600 Area	WNP-1
Latitude	46°39'35.88"	46°33'22.33"	46°33'22.33"	46°22'14.09"	46°26'2.31"	46°23'37.94"	46°27'58.01"
Longitude	-119°36'32.33"	-119°37'43.30"	-119°32'44.96"	-119°16'40.9"	-119°21'27.50"	-119°32'0.52"	-119°18'44.30"
Release Height	12.8 m	61.0 m	61.0 m	17.9 m	14.3 m	Ground Level	Ground Level

Distance and Atmospheric Dispersion at Site Boundary														
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	8,727	4.0×10^{-8}	17,234	4.6×10^{-9}	22,325	3.4×10^{-9}	9,361	2.8×10^{-8}	16,086	1.5×10^{-8}	38,245	5.7×10^{-9}	10,853	3.1×10^{-8}
NNE	12,004	2.1×10^{-8}	24,489	2.2×10^{-9}	25,670	2.1×10^{-9}	2,388	1.3×10^{-7}	12,934	1.6×10^{-8}	30,461	6.4×10^{-9}	7,855	4.0×10^{-8}
NE	17,712	2.2×10^{-8}	26,784	3.6×10^{-9}	20,224	4.9×10^{-9}	1,587	3.7×10^{-7}	9,821	4.2×10^{-8}	25,390	1.4×10^{-8}	5,295	1.2×10^{-7}
ENE	20,510	2.8×10^{-8}	24,022	6.2×10^{-9}	17,492	8.7×10^{-9}	1,413	6.5×10^{-7}	7,922	8.6×10^{-8}	22,039	2.7×10^{-8}	4,865	2.2×10^{-7}
E	20,590	4.6×10^{-8}	23,513	9.1×10^{-9}	17,205	1.3×10^{-8}	1,407	9.4×10^{-7}	7,817	1.4×10^{-7}	7,861	1.8×10^{-7}	4,216	4.5×10^{-7}
ESE	22,165	4.3×10^{-8}	28,561	8.5×10^{-9}	22,180	1.1×10^{-8}	1,492	9.8×10^{-7}	7,846	1.5×10^{-7}	5,867	2.8×10^{-7}	4,212	4.5×10^{-7}
SE	31,482	2.2×10^{-8}	24,266	9.1×10^{-9}	26,251	8.4×10^{-9}	1,883	6.9×10^{-7}	8,746	1.1×10^{-7}	2,748	7.2×10^{-7}	5,313	2.7×10^{-7}
SSE	32,668	8.5×10^{-9}	20,740	5.7×10^{-9}	21,058	5.6×10^{-9}	2,147	2.8×10^{-7}	9,120	4.2×10^{-8}	2,266	4.1×10^{-7}	7,248	7.0×10^{-8}
S	26,544	1.6×10^{-8}	14,929	9.8×10^{-9}	19,177	7.4×10^{-9}	2,137	3.5×10^{-7}	7,915	6.9×10^{-8}	2,225	5.7×10^{-7}	12,429	4.5×10^{-8}
SSW	25,867	8.7×10^{-9}	15,132	5.3×10^{-9}	16,507	4.8×10^{-9}	2,241	1.8×10^{-7}	7,482	4.1×10^{-8}	2,841	2.1×10^{-7}	12,298	2.5×10^{-8}
SW	17,092	7.2×10^{-9}	14,979	3.7×10^{-9}	17,560	3.0×10^{-9}	2,560	8.5×10^{-8}	7,422	2.0×10^{-8}	2,626	1.2×10^{-7}	12,393	1.2×10^{-8}
WSW	15,068	7.9×10^{-9}	12,638	4.0×10^{-9}	19,118	2.4×10^{-9}	3,677	4.6×10^{-8}	12,536	9.0×10^{-9}	3,709	6.4×10^{-8}	17,723	6.5×10^{-9}
W	10,665	2.7×10^{-8}	12,346	8.9×10^{-9}	18,701	5.3×10^{-9}	5,874	5.1×10^{-8}	19,209	1.1×10^{-8}	4,804	1.2×10^{-7}	25,540	8.5×10^{-9}
WNW	8,593	3.2×10^{-8}	12,546	6.9×10^{-9}	18,995	4.1×10^{-9}	27,312	5.3×10^{-9}	33,445	4.5×10^{-9}	6,527	5.0×10^{-8}	37,072	4.5×10^{-9}
NW	7,289	7.9×10^{-8}	14,910	9.9×10^{-9}	19,803	7.1×10^{-9}	46,357	5.2×10^{-9}	38,932	7.2×10^{-9}	23,021	1.7×10^{-8}	38,585	8.3×10^{-9}
NNW	7,399	7.3×10^{-8}	15,721	8.0×10^{-9}	19,540	6.2×10^{-9}	47,598	4.7×10^{-9}	39,255	6.7×10^{-9}	33,663	9.5×10^{-9}	36,707	8.5×10^{-9}

[a] See Figure M.2.4–1 for location of release points.

Note: Release from the 600 Area are conservatively assumed to be near Rattlesnake Mountain.

Source: HNUS 1996a.

Table M.2.4–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Hanford Site Boundary

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: 100 Area			
100 Area	NW	7,289	7.9×10^{-8}
200 West	W	12,214	2.3×10^{-8}
200 East	ESE	23,726	3.9×10^{-8}
300 Area	SE	42,124	1.5×10^{-8}
400 Area	SE	37,783	1.8×10^{-8}
600 Area	S	32,656	1.2×10^{-8}
WNP-1	SE	34,885	1.9×10^{-8}
Release Point: 200 West			
100 Area	N	17,235	4.6×10^{-9}
200 West	NW	14,910	9.9×10^{-9}
200 East	E	23,514	9.1×10^{-9}
300 Area	SE	35,271	6.0×10^{-9}
400 Area	ESE	32,194	7.5×10^{-9}
600 Area	SSE	22,149	5.3×10^{-9}
WNP-1	ESE	30,381	7.9×10^{-9}
Release Point: 200 East			
100 Area	NNW	19,541	6.2×10^{-9}
200 West	WNW	19,965	3.9×10^{-9}
200 East	E	17,205	1.3×10^{-8}
300 Area	SE	30,363	7.1×10^{-9}
400 Area	SE	26,701	8.2×10^{-9}
600 Area	S	20,407	6.9×10^{-9}
WNP-1	ESE	34,885	6.9×10^{-9}
Release Point: 300 Area			
100 Area	NW	48,259	4.9×10^{-9}
200 West	NW	48,764	4.9×10^{-9}
200 East	N	23,223	8.4×10^{-9}
300 Area	ESE	1,493	9.8×10^{-7}
400 Area	NNE	5,963	4.0×10^{-8}
600 Area	W	18,045	1.1×10^{-8}
WNP-1	N	10,083	2.5×10^{-8}

Table M.2.4–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Hanford Site Boundary—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: 400 Area			
100 Area	NW	38,933	$7.2x10^{-9}$
200 West	NW	39,581	$7.0x10^{-9}$
200 East	N	16,127	$1.5x10^{-8}$
300 Area	SE	10,547	$8.3x10^{-8}$
400 Area	ESE	7,846	$1.5x10^{-7}$
600 Area	WSW	13,655	$8.0x10^{-9}$
WNP-1	ENE	8,188	$8.2x10^{-8}$
Release Point: 600 Area			
100 Area	NNW	36,551	$8.6x10^{-9}$
200 West	NNW	33,674	$9.5x10^{-9}$
200 East	NE	25,978	$1.4x10^{-8}$
300 Area	E	21,313	$4.6x10^{-8}$
400 Area	E	21,493	$4.6x10^{-8}$
600 Area	SE	2,748	$7.2x10^{-7}$
WNP-1	ENE	22,418	$2.6x10^{-8}$
Release Point: WNP-1			
100 Area	NW	38,611	$8.3x10^{-9}$
200 West	WNW	40,473	$4.0x10^{-9}$
200 East	N	12,370	$2.6x10^{-8}$
300 Area	SSE	11,643	$3.5x10^{-8}$
400 Area	SE	6,472	$2.0x10^{-7}$
600 Area	WSW	18,493	$6.2x10^{-9}$
WNP-1	E	4,216	$4.5x10^{-7}$

Source: HNUS 1996a.

$2.4x10^{-8}$ would result from 50 years of operation. The population would receive a dose of 1.1 person-rem in 2030. An estimated 0.028 fatal cancers could result from 50 years of operation.

Worker Doses and Health Effects. Based on measured values during 1991 and 1992, it is estimated that the average dose to a badged worker involved in No Action activities at Hanford in 2005 and beyond would equal 27 mrem. It is projected that in 2005 and beyond, there would be 9,300 badged workers involved in No Action activities. The annual dose among all these workers would equal 250 person-rem. From 50 years of operation, an estimated fatal cancer risk of $5.5x10^{-4}$ would result to the average worker and 5.1 fatal cancers could result among all workers.

Table M.2.4–3. Doses and Resulting Health Effects to the Maximally Exposed Individual at Hanford Site From Atmospheric Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	9.9×10^{-4}	2.9×10^{-3}	4.2×10^{-4}	1.4×10^{-6}	4.4×10^{-3}[b]	1.5×10^{-3}	2.2×10^{-9}
Upgraded Storage Facility-200 West[c]	3.9×10^{-7}	8.5×10^{-9}	2.3×10^{-15}	3.4×10^{-12}	4.0×10^{-7}	1.3×10^{-7}	2.0×10^{-13}
Upgraded Storage Facility-Fuels and Materials Examination Facility[c]	1.7×10^{-6}	3.8×10^{-8}	1.0×10^{-14}	1.6×10^{-11}	1.8×10^{-6}	6.0×10^{-7}	9.0×10^{-13}
Consolidated Storage Facility	2.5×10^{-6}	4.4×10^{-9}	9.6×10^{-16}	2.0×10^{-12}	2.5×10^{-6}	8.3×10^{-7}	1.2×10^{-12}
Collocated Storage Facility	2.5×10^{-6}	4.4×10^{-9}	1.0×10^{-15}	3.0×10^{-12}	2.5×10^{-6}	8.3×10^{-7}	1.2×10^{-12}
Pit Disassembly/Conversion Facility	2.8×10^{-4}	6.3×10^{-6}	1.6×10^{-12}	2.5×10^{-9}	2.9×10^{-4}	9.7×10^{-5}	1.4×10^{-10}
Pu Conversion Facility	1.8×10^{-4}	3.4×10^{-7}	7.7×10^{-14}	1.6×10^{-10}	1.8×10^{-4}	6.0×10^{-5}	9.0×10^{-11}
MOX Fuel Fabrication Facility	1.4×10^{-4}	2.4×10^{-7}	5.2×10^{-14}	2.5×10^{-10}	1.4×10^{-4}	4.7×10^{-5}	7.0×10^{-11}
Ceramic Immobilization Facility (Immobilized Disposition)	3.2×10^{-8}	5.6×10^{-11}	1.2×10^{-17}	2.5×10^{-14}	3.2×10^{-8}	1.1×10^{-8}	1.6×10^{-14}
Deep Borehole Complex (Direct Disposition)	5.3×10^{-9}	7.6×10^{-11}	2.0×10^{-17}	3.1×10^{-14}	5.3×10^{-9}	1.8×10^{-9}	2.7×10^{-15}
Deep Borehole Complex (Immobilized Disposition)	6.6×10^{-9}	1.1×10^{-10}	3.0×10^{-17}	4.5×10^{-14}	6.7×10^{-9}	2.2×10^{-9}	3.4×10^{-15}
Vitrification Facility	1.3×10^{-5}	8.6×10^{-7}	2.5×10^{-10}	1.3×10^{-7}	1.4×10^{-5}	4.7×10^{-6}	7.0×10^{-12}
Ceramic Immobilization Facility (Ceramic Immobilization)	3.6×10^{-8}	1.7×10^{-7}	5.1×10^{-11}	2.8×10^{-8}	2.3×10^{-7}	7.7×10^{-8}	1.2×10^{-13}
Advanced Boiling Water Reactor	5.4×10^{-3}	3.2×10^{-1}	1.2×10^{-1}	7.1×10^{-3}	4.5×10^{-1}	1.5×10^{-1}	2.3×10^{-7}
CE System 80+ Reactor	1.1×10^{-2}	3.1×10^{-1}	8.7×10^{-3}	1.5×10^{-4}	3.3×10^{-1}	1.1×10^{-1}	1.7×10^{-7}
[Text deleted.]							
AP600 Reactor	2.5×10^{-3}	2.1×10^{-1}	2.5×10^{-2}	1.5×10^{-3}	2.3×10^{-1}	7.7×10^{-2}	1.2×10^{-7}
RESAR 90 Reactor	8.9×10^{-3}	3.2×10^{-1}	1.0×10^{-2}	1.7×10^{-3}	3.4×10^{-1}	1.1×10^{-1}	1.7×10^{-7}

[a] Individual annual natural background radiation dose is equal to 300 mrem.

[b] The storage facility contributes 4.1×10^{-4} mrem/year.

[c] The radiological impacts for the Upgrade Alternative are calculated based on measured releases from facilities at Hanford, RFETS, and LANL.

[Text deleted.]

Source: HNUS 1996a.

Table M.2.4–4. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Hanford Site From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	5.2×10^{-2}	4.1×10^{-1}	4.7×10^{-3}	1.5×10^{-4}	4.6×10^{-1}[b]	2.3×10^{-4}	2.3×10^{-4}
Upgraded Storage Facility-200 West[c]	2.8×10^{-5}	7.6×10^{-6}	1.6×10^{-13}	2.4×10^{-10}	3.5×10^{-5}	1.9×10^{-8}	1.8×10^{-8}
Upgraded Storage Facility-Fuels Materials Examination Facility[c]	3.6×10^{-5}	1.1×10^{-5}	2.1×10^{-13}	3.2×10^{-10}	4.7×10^{-5}	2.5×10^{-8}	2.4×10^{-8}
Consolidated Storage Facility	1.1×10^{-4}	2.9×10^{-6}	4.2×10^{-14}	8.8×10^{-11}	1.1×10^{-4}	5.9×10^{-8}	5.5×10^{-8}
Collocated Storage Facilities	1.1×10^{-4}	2.9×10^{-6}	4.5×10^{-14}	1.3×10^{-10}	1.1×10^{-4}	5.9×10^{-8}	5.5×10^{-8}
Pit Disassembly/Conversion Facility	1.2×10^{-2}	4.1×10^{-3}	7.2×10^{-11}	1.1×10^{-7}	1.6×10^{-2}	8.6×10^{-6}	8.0×10^{-6}
Pu Conversion Facility	8.2×10^{-3}	2.3×10^{-4}	3.4×10^{-12}	7.2×10^{-9}	8.4×10^{-3}	4.5×10^{-6}	4.2×10^{-6}
MOX Fuel Fabrication Facility	6.0×10^{-3}	1.6×10^{-4}	2.3×10^{-12}	1.1×10^{-8}	6.2×10^{-3}	3.3×10^{-6}	3.1×10^{-6}
Ceramic Immobilization Facility (Immobilized Disposition)	1.4×10^{-6}	3.6×10^{-8}	5.6×10^{-16}	1.1×10^{-12}	1.5×10^{-6}	8.0×10^{-10}	7.5×10^{-10}
Deep Borehole Complex (Direct Disposition)	2.3×10^{-7}	5.0×10^{-8}	8.8×10^{-16}	1.3×10^{-12}	2.8×10^{-7}	1.5×10^{-10}	1.4×10^{-10}
Deep Borehole Complex (Immobilized Disposition)	2.9×10^{-7}	7.4×10^{-8}	1.3×10^{-15}	2.0×10^{-12}	3.7×10^{-7}	2.0×10^{-10}	1.9×10^{-10}
Vitrification Facility	5.8×10^{-4}	2.0×10^{-4}	1.1×10^{-8}	6.1×10^{-6}	7.9×10^{-4}	4.2×10^{-7}	4.0×10^{-7}
Ceramic Immobilization Facility (Ceramic Immobilization)	1.6×10^{-6}	3.6×10^{-5}	2.2×10^{-9}	1.2×10^{-6}	3.9×10^{-5}	2.1×10^{-8}	1.9×10^{-8}
Advanced Boiling Water Reactor	2.9×10^{-2}	2.6×10^{1}	3.0×10^{-1}	3.5×10^{-2}	2.6×10^{1}	1.4×10^{-2}	1.3×10^{-2}
CE System 80+ Reactor	7.2×10^{-2}	3.0×10^{1}	4.0×10^{-2}	9.3×10^{-4}	3.0×10^{1}	1.6×10^{-2}	1.5×10^{-2}
[Text deleted.]							
AP600 Reactor	1.6×10^{-2}	2.0×10^{1}	1.3×10^{-1}	9.6×10^{-3}	2.0×10^{1}	1.1×10^{-2}	1.0×10^{-2}
RESAR 90 Reactor	5.8×10^{-2}	2.9×10^{1}	5.4×10^{-2}	1.1×10^{-2}	2.9×10^{1}	1.6×10^{-2}	1.5×10^{-2}

[a] Dose to the population within 80 km from natural background radiation in the year 2030 is equal to 186,400 person-rem.

[b] The storage facility contributes 0.047 person-rem/year.

[c] The radiological impacts for the Upgrade Alternative are calculated based on measured releases from facilities at Hanford, RFETS, and LANL.

[Text deleted.]

Source: HNUS 1996a.

Table M.2.4–5. Doses and Resulting Health Effects to the Maximally Exposed Individual at Hanford Site From Liquid Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)						Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Fish Ingestion	Other Food Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	5.2×10^{-4}	4.2×10^{-4}	0	1.1×10^{-8}	2.1×10^{-8}	3.2×10^{-6}	9.5×10^{-4}[b]	3.2×10^{-4}	4.8×10^{-10}
Advanced Boiling Water Reactor	4.6×10^{-3}	9.5×10^{-5}	0	1.1×10^{-7}	2.2×10^{-7}	1.2×10^{-5}	4.7×10^{-3}	1.6×10^{-3}	2.3×10^{-9}
CE System 80+ Reactor	1.4×10^{-2}	4.8×10^{-4}	0	2.1×10^{-7}	4.3×10^{-7}	3.3×10^{-5}	1.4×10^{-2}	4.8×10^{-3}	7.2×10^{-9}
AP600 Reactor	2.2×10^{-2}	7.9×10^{-4}	0	2.4×10^{-7}	4.8×10^{-7}	3.5×10^{-5}	2.4×10^{-2}	7.9×10^{-3}	1.2×10^{-8}
[Text deleted.]									
RESAR-90 Reactor	1.5×10^{-2}	8.9×10^{-4}	0	2.4×10^{-7}	4.7×10^{-7}	2.0×10^{-5}	1.6×10^{-2}	5.3×10^{-3}	7.9×10^{-9}

[a] Individual annual natural background radiation dose is equal to 300 mrem.

[b] The storage facility does not contribute to the dose.

Source: HNUS 1996a.

Table M.2.4–6. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Hanford Site From Liquid Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)						Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Fish Ingestion	Other Food Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	1.9×10^{-4}	1.1	1.0×10^{-3}	6.8×10^{-8}	2.7×10^{-7}	1.4×10^{-5}	1.1[b]	7.3×10^{-4}	5.5×10^{-4}
Advanced Boiling Water Reactor	1.7×10^{-3}	3.3×10^{-1}	1.7×10^{-3}	6.9×10^{-7}	2.7×10^{-6}	5.2×10^{-5}	3.3×10^{-1}	2.2×10^{-4}	1.7×10^{-4}
CE System 80+ Reactor	5.1×10^{-3}	1.5	1.1×10^{-2}	1.3×10^{-6}	5.3×10^{-6}	1.4×10^{-4}	1.5	1.0×10^{-3}	7.6×10^{-4}
AP600 Reactor	8.7×10^{-3}	2.6	1.9×10^{-2}	1.5×10^{-6}	6.0×10^{-6}	1.5×10^{-4}	2.6	1.7×10^{-3}	1.3×10^{-3}
[Text deleted.]									
RESAR-90 Reactor	5.5×10^{-3}	2.7	2.4×10^{-2}	1.5×10^{-6}	6.0×10^{-6}	8.5×10^{-5}	2.7	1.8×10^{-3}	1.4×10^{-3}

[a] Dose to the population within 80 km from natural background radiation in the year 2030 is equal to 186,400 person-rem.

[b] The storage facility does not contribute to the dose.

Source: HNUS 1996a.

Table M.2.4.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Hanford Site (curies)

Isotope	100 Area	200 East	200 West[a]	300 Area	400 Area	600 Area	No Action Storage
H-3	0	0	0	11.6	2.10	0	0
[Text deleted.]							
Co-60	5.22×10^{-6}	0	0	1.40×10^{-8}	0	0	0
Sr-90	5.43×10^{-5}	1.44×10^{-4}	8.4×10^{-5}	4.15×10^{-5}	0	1.80×10^{-7}	4.4×10^{-5}
Ru-106	1.31×10^{-5}	0	0	0	0	0	0
Sb-125	6.01×10^{-6}	0	0	1.51×10^{-6}	0	0	0
I-129	0	4.85×10^{-3}	4.0×10^{-6}	0	0	0	0
Cs-134	8.89×10^{-8}	0	0	3.30×10^{-7}	0	0	0
Cs-137	1.61×10^{-4}	1.50×10^{-3}	2.3×10^{-4}	9.34×10^{-7}	8.22×10^{-6}	0	0
Pm-147	0	1.10×10^{-4}	0	0	0	0	0
Eu-154	6.28×10^{-6}	0	0	1.49×10^{-6}	0	0	0
Eu-155	2.84×10^{-6}	0	0	2.60×10^{-8}	0	0	0
Pb-212	0	9.70×10^{-4}	0	0	0	0	0
Rn-222	0	0	0	1.50	0	0	0
[Text deleted.]							
Pu-238	1.03×10^{-6}	3.20×10^{-6}	0	6.85×10^{-8}	0	0	0
Pu-239	8.21×10^{-6}	1.12×10^{-5}	3.8×10^{-5}	8.44×10^{-6}	2.38×10^{-6}	4.00×10^{-8}	5.1×10^{-4}
Pu-241	0	3.30×10^{-5}	0	0	0	0	3.4×10^{-3}
Am-241	5.41×10^{-6}	2.78×10^{-5}	5.5×10^{-6}	5.51×10^{-8}	0	0	9.4×10^{-5}

[a] Presented releases do not include those associated with storage operations.
Source: HF PNL 1994b.

Table M.2.4.1–2. Annual Liquid Releases From Normal Operation of No Action at Hanford Site (curies)

Isotope	Release[a]
H-3	0.38
Co-60	3.6×10^{-4}
Sr-90	0.11
Ru-106	1.6×10^{-3}
Sb-125	1.3×10^{-4}
Cs-134	4.7×10^{-5}
Cs-137	4.4×10^{-4}
Pu-239	1.4×10^{-7}

[a] Total site release.
Source: HF PNL 1994b.

M.2.4.2 Storage and Disposition

Atmospheric Releases and Resulting Impacts to the Public. Total site radiological impacts during operation of storage or disposition facilities can be found by adding the impacts resulting from No Action facilities to the changes in impacts resulting from storage or disposition facilities. For example, to determine the radiological impact for the addition of the AP600 reactor at Hanford, the No Action facilities doses would be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases for the storage and disposition facilities are given in Section M.2.3. Tables M.2.4–3 and M.2.4–4 include the atmospheric radiological impacts by alternative facility.

The annual doses associated with the different alternative facilities range from 5.3×10^{-9} to 0.45 mrem to the maximally exposed member of the public and from 2.8×10^{-7} to 30 person-rem to the 80-km (50-mi) population in 2030. The associated health effects from annual operations are included in both tables.

Liquid Releases and Resulting Impacts to the Public. There are two disposition technologies that would release liquid discharges to the surface water surrounding Hanford. These are the large and small evolutionary LWRs. The liquid releases for these technologies are given in Section M.2.3. As an example of determining the total site liquid radiological impact associated with the addition of an AP600 reactor at Hanford, the No Action liquid doses must be summed with the AP600 reactor liquid doses. Tables M.2.4–5 and M.2.4–6 present the liquid radiological impacts for the applicable alternative facilities.

The annual doses associated with the different LWR's that have liquid releases range from 4.7×10^{-3} to 0.024 mrem to the maximally exposed member of the public, and range from 0.33 to 2.7 person-rem to the downstream population in 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the changes in impacts from the storage or disposition facilities to determine the impacts from total site operation (refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.5 RADIOLOGICAL IMPACTS AT NEVADA TEST SITE

This section presents the radiological impacts of the various storage and disposition alternatives at NTS. Section M.2.5.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.5.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modeling, NTS was divided into six separate areas which would release radioactivity in 2005. All release points in each area were aggregated into a single release point. Table M.2.5–1 presents the characteristics of each of the release points including location, release height, and minimum distance and annual average dispersion to the site boundary in each of the 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For further clarification on the definition of "maximum receptor" refer to Section M.2.2.2. For example, the dose resulting from releases for Areas 5, 9, 12, 19, and Device Assembly Facility has been determined from the maximum receptor for Area 3. Figure M.2.5–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred to the site MEI) is then determined by the maximum dose to one of these maximum receptors. Table M.2.5–2 presents the direction, distance, and atmospheric dispersion from each release point to each of the maximum receptors. Annual radiological releases were assumed to remain constant during the full operational period.

The population and food stuffs distributions centered on each release area are provided in a Health Risk Data report, October 1996. The joint frequency distribution used for the dose assessment was based on the meteorological measurements for 1990 from the Desert Rock at the 10-m (33-ft) height and is contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables, and for the projected operational period in the text. Tables M.2.5–3 and M.2.5–4 include the radiological impacts to the public from atmospheric release for No Action and the storage and disposition alternatives.

Table M.2.5–1. Release Point Characteristics, Direction, Distance, and Chi/Q at Nevada Test Site

Release Point[a]	Area 3		Area 5		Area 9		Area 12		Area 19		DAF	
Latitude	37°2'52.858"		36°51'17.933"		37°7'40.938"		37°13'9.788"		37°15'14.317"		6°53'37.824"	
Longitude	-116°0'23.131"		-115°57'12.384"		-116°2'5.827"		-116°9'20.893"		-116°18'59.322"		-116°2'54.794"	
Release Height	Ground Level		Ground Level		Ground Level		Ground Level		Ground Level		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary											
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	22,334	$9.6x10^{-9}$	11,017	$2.5x10^{-8}$	13,494	$1.9x10^{-8}$	3,598	$1.2x10^{-7}$	14,593	$1.7x10^{-8}$	39,497	$4.6x10^{-9}$
NNE	12,393	$2.3x10^{-8}$	4,008	$1.1x10^{-7}$	13,751	$2.0x10^{-8}$	3,666	$1.3x10^{-7}$	13,493	$2.0x10^{-8}$	19,043	$1.3x10^{-8}$
NE	8,331	$5.3x10^{-8}$	2,719	$2.7x10^{-7}$	11,367	$3.5x10^{-8}$	4,317	$1.3x10^{-7}$	13,488	$2.8x10^{-8}$	12,827	$2.9x10^{-8}$
ENE	7,092	$5.7x10^{-8}$	2,290	$3.0x10^{-7}$	9,692	$3.7x10^{-8}$	6,382	$6.6x10^{-8}$	11,870	$2.8x10^{-8}$	10,926	$3.2x10^{-8}$
E	6,970	$5.6x10^{-8}$	2,249	$2.9x10^{-7}$	9,518	$3.7x10^{-8}$	17,654	$1.6x10^{-8}$	11,646	$2.8x10^{-8}$	10,734	$3.1x10^{-8}$
ESE	7,124	$4.6x10^{-8}$	2,307	$2.4x10^{-7}$	9,727	$3.0x10^{-8}$	20,667	$1.1x10^{-8}$	35,224	$5.4x10^{-9}$	10,975	$2.5x10^{-8}$
SE	8,470	$3.3x10^{-8}$	2,736	$1.7x10^{-7}$	11,519	$2.2x10^{-8}$	24,525	$7.9x10^{-9}$	41,754	$3.9x10^{-9}$	13,007	$1.8x10^{-8}$
SSE	12,801	$2.1x10^{-8}$	4,119	$1.0x10^{-7}$	17,407	$1.4x10^{-8}$	37,017	$5.2x10^{-9}$	63,001	$2.6x10^{-9}$	19,622	$1.2x10^{-8}$
S	37,774	$6.3x10^{-9}$	12,182	$2.8x10^{-8}$	50,960	$4.3x10^{-9}$	61,111	$3.4x10^{-9}$	58,791	$3.6x10^{-9}$	27,780	$9.4x10^{-9}$
SSW	43,741	$5.7x10^{-9}$	26,724	$1.1x10^{-8}$	52,085	$4.6x10^{-9}$	46,477	$5.3x10^{-9}$	20,820	$1.5x10^{-8}$	26,284	$1.1x10^{-8}$
SW	47,205	$6.4x10^{-9}$	26,537	$4.0x10^{-9}$	44,107	$7.0x10^{-9}$	31,082	$1.1x10^{-8}$	15,876	$2.7x10^{-8}$	30,390	$1.1x10^{-8}$
WSW	40,053	$5.6x10^{-9}$	38,554	$5.9x10^{-9}$	37,377	$6.1x10^{-9}$	27,130	$9.3x10^{-9}$	15,771	$1.9x10^{-8}$	36,372	$6.3x10^{-9}$
W	39,283	$8.1x10^{-9}$	44,204	$6.9x10^{-9}$	36,657	$8.8x10^{-9}$	27,851	$1.3x10^{-8}$	16,416	$2.6x10^{-8}$	35,698	$9.1x10^{-9}$
WNW	40,055	$8.1x10^{-9}$	45,100	$7.0x10^{-9}$	40,648	$8.0x10^{-9}$	28,395	$1.3x10^{-8}$	18,231	$2.3x10^{-8}$	36,413	$9.2x10^{-9}$
NW	27,062	$7.7x10^{-9}$	53,212	$3.2x10^{-9}$	16,370	$1.5x10^{-8}$	4,360	$9.3x10^{-8}$	15,211	$1.6x10^{-8}$	42,950	$4.2x10^{-9}$
NNW	22,808	$4.2x10^{-9}$	44,582	$1.8x10^{-9}$	13,801	$8.2x10^{-9}$	3,679	$5.2x10^{-8}$	14,912	$7.4x10^{-9}$	40,381	$2.0x10^{-9}$

[a] See Figure M.2.5–1 for location of release points.

Source: HNUS 1996a.

Table M.2.5–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Nevada Test Site Boundary

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: Area 3			
Area 3	ENE	7,093	$5.7x10^{-8}$
Area 5	SSE	22,117	$1.0x10^{-8}$
Area 9	NNE	12,766	$2.2x10^{-8}$
Area 12	NNW	25,015	$3.8x10^{-9}$
Area 19	NNW	29,688	$3.0x10^{-9}$
DAF	SSE	16,601	$1.5x10^{-8}$
Release Point: Area 5			
Area 3	N	22,849	$9.3x10^{-9}$
Area 5	ENE	2,291	$3.0x10^{-7}$
Area 9	N	32,178	$6.0x10^{-9}$
Area 12	NNW	46,638	$1.7x10^{-9}$
Area 19	NNW	50,866	$1.5x10^{-9}$
DAF	NNE	6,740	$5.3x10^{-8}$
Release Point: Area 9			
Area 3	SE	12,141	$2.0x10^{-8}$
Area 5	SSE	31,344	$6.4x10^{-9}$
Area 9	ENE	9,692	$3.7x10^{-8}$
Area 12	NNW	15,986	$6.8x10^{-9}$
Area 19	NW	20,987	$1.1x10^{-8}$
DAF	SSE	25,762	$8.3x10^{-9}$
Release Point: Area 12			
Area 3	SE	26,875	$7.0x10^{-9}$
Area 5	SSE	44,834	$4.0x10^{-9}$
Area 9	ESE	21,893	$1.0x10^{-8}$
Area 12	NE	4,318	$1.3x10^{-7}$
Area 19	NNW	6,614	$2.3x10^{-8}$
DAF	SSE	39,639	$4.7x10^{-9}$
Release Point: Area 19			
Area 3	ESE	40,661	$4.4x10^{-9}$
Area 5	SE	55,804	$2.7x10^{-9}$
Area 9	ESE	36,584	$5.1x10^{-9}$
Area 12	E	16,711	$1.7x10^{-8}$
Area 19	ENE	11,871	$2.8x10^{-8}$
DAF	SE	51,278	$3.0x10^{-9}$
Release Point: DAF			
Area 3	NNE	21,318	$1.1x10^{-8}$
Area 5	SSE	11,411	$2.4x10^{-8}$
Area 9	NNE	29,792	$7.4x10^{-9}$
Area 12	N	40,290	$4.5x10^{-9}$
Area 19	NNW	43,910	$1.8x10^{-9}$
DAF	ENE	10,927	$3.2x10^{-8}$

Source: HNUS 1996a.

Table M.2.5–3. Doses and Resulting Health Effects to the Maximally Exposed Individual at Nevada Test Site From Atmospheric Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	4.2×10^{-3}	1.2×10^{-5}	2.9×10^{-7}	2.2×10^{-9}	4.2×10^{-3}	1.3×10^{-3}	2.1×10^{-9}
Consolidated Storage Facility (P-Tunnel)	5.5×10^{-6}	9.6×10^{-9}	2.1×10^{-15}	4.4×10^{-12}	5.6×10^{-6}	1.8×10^{-6}	2.8×10^{-12}
Collocated Storage Facilities (P-Tunnel)	5.6×10^{-6}	9.6×10^{-9}	2.2×10^{-15}	6.6×10^{-12}	5.6×10^{-6}	1.8×10^{-6}	2.8×10^{-12}
Consolidated Storage Facility	1.3×10^{-6}	2.2×10^{-9}	4.9×10^{-16}	1.0×10^{-12}	1.3×10^{-6}	4.2×10^{-7}	6.5×10^{-13}
Collocated Storage Facilities	1.3×10^{-6}	2.3×10^{-9}	5.2×10^{-16}	1.6×10^{-12}	1.3×10^{-6}	4.2×10^{-7}	6.5×10^{-13}
Pit Disassembly/ Conversion Facility	1.4×10^{-4}	3.2×10^{-6}	8.6×10^{-13}	1.3×10^{-9}	1.5×10^{-4}	4.8×10^{-5}	7.5×10^{-11}
Pu Conversion Facility	9.5×10^{-5}	1.7×10^{-7}	3.9×10^{-14}	8.3×10^{-11}	9.5×10^{-5}	3.0×10^{-5}	4.8×10^{-11}
MOX Fuel Fabrication Facility	6.8×10^{-5}	1.2×10^{-7}	2.6×10^{-14}	1.3×10^{-10}	6.8×10^{-5}	2.2×10^{-5}	3.4×10^{-11}
Ceramic Immobilization Facility (Immobilized Disposition)	1.6×10^{-8}	2.8×10^{-11}	6.4×10^{-18}	1.3×10^{-14}	1.6×10^{-8}	5.1×10^{-9}	8.0×10^{-15}
Deep Borehole Complex (Direct Disposition)	2.7×10^{-9}	3.9×10^{-11}	1.0×10^{-17}	1.5×10^{-14}	2.7×10^{-9}	8.6×10^{-10}	1.4×10^{-15}
Deep Borehole Complex (Immobilized Disposition)	3.3×10^{-9}	5.8×10^{-11}	1.5×10^{-17}	2.3×10^{-14}	3.4×10^{-9}	1.1×10^{-9}	1.7×10^{-15}
Vitrification Facility	6.6×10^{-6}	4.3×10^{-7}	1.3×10^{-10}	7.1×10^{-8}	7.2×10^{-6}	2.3×10^{-6}	3.6×10^{-12}
Ceramic Immobilization Facility (Ceramic Immobilization)	1.8×10^{-8}	8.5×10^{-8}	2.5×10^{-11}	1.4×10^{-8}	1.2×10^{-7}	3.8×10^{-8}	6.0×10^{-14}
Advanced Boiling Water Reactor	4.6×10^{-4}	2.3×10^{-2}	6.2×10^{-3}	5.7×10^{-4}	3.0×10^{-2}	9.6×10^{-3}	1.5×10^{-8}
CE System 80+ Reactor	1.4×10^{-3}	2.6×10^{-2}	5.7×10^{-4}	2.2×10^{-4}	2.9×10^{-2}	9.3×10^{-3}	1.5×10^{-8}
[Text deleted.]							
AP600 Reactor	7.4×10^{-4}	2.2×10^{-2}	1.7×10^{-3}	3.4×10^{-4}	2.5×10^{-2}	8.0×10^{-3}	1.3×10^{-8}
RESAR-90 Reactor	1.2×10^{-3}	3.2×10^{-2}	7.0×10^{-4}	2.8×10^{-4}	3.4×10^{-2}	1.1×10^{-2}	1.7×10^{-8}

[a] Individual annual natural background radiation dose is equal to 313 mrem.

Source: HNUS 1996a.

Table M.2.5–4. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Nevada Test Site From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	3.7×10^{-3}	9.4×10^{-6}	3.6×10^{-6}	1.9×10^{-9}	3.7×10^{-3}	4.0×10^{-5}	1.9×10^{-6}
Consolidated Storage Facility (P-Tunnel)	1.7×10^{-6}	1.8×10^{-11}	6.6×10^{-16}	1.4×10^{-12}	1.7×10^{-6}	1.8×10^{-8}	8.5×10^{-10}
Collocated Storage Facility (P-Tunnel)	1.7×10^{-6}	1.9×10^{-11}	7.0×10^{-16}	2.1×10^{-12}	1.7×10^{-6}	1.8×10^{-8}	8.5×10^{-10}
Consolidated Storage Facility	2.6×10^{-6}	5.8×10^{-11}	1.0×10^{-15}	2.1×10^{-12}	2.6×10^{-6}	2.8×10^{-8}	1.3×10^{-9}
Collocated Storage Facilities	2.6×10^{-6}	6.2×10^{-11}	1.1×10^{-15}	3.2×10^{-12}	2.6×10^{-6}	2.8×10^{-8}	1.3×10^{-9}
Pit Disassembly/ Conversion Facility	2.9×10^{-4}	8.4×10^{-8}	1.7×10^{-12}	2.6×10^{-9}	2.9×10^{-4}	3.2×10^{-6}	1.5×10^{-7}
Pu Conversion Facility	1.9×10^{-4}	4.6×10^{-9}	8.0×10^{-14}	1.7×10^{-10}	1.9×10^{-4}	2.1×10^{-6}	9.5×10^{-8}
MOX Fuel Fabrication Facility	1.4×10^{-4}	3.4×10^{-9}	5.4×10^{-14}	2.6×10^{-10}	1.4×10^{-4}	1.5×10^{-6}	7.0×10^{-8}
Ceramic Immobilization Facility (Immobilized Disposition)	3.3×10^{-8}	7.2×10^{-13}	1.3×10^{-17}	2.7×10^{-14}	3.3×10^{-8}	3.6×10^{-10}	1.7×10^{-11}
Deep Borehole Complex (Direct Disposition)	5.3×10^{-9}	1.0×10^{-12}	2.1×10^{-17}	3.2×10^{-14}	5.3×10^{-9}	5.8×10^{-11}	2.7×10^{-12}
Deep Borehole Complex (Immobilized Disposition)	6.6×10^{-9}	1.5×10^{-12}	3.1×10^{-17}	4.8×10^{-14}	6.6×10^{-9}	7.2×10^{-11}	3.3×10^{-12}
Vitrification Facility	1.3×10^{-5}	5.2×10^{-7}	2.6×10^{-10}	1.4×10^{-7}	1.4×10^{-5}	1.5×10^{-7}	7.0×10^{-9}
Ceramic Immobilization Facility (Ceramic Immobilization)	3.7×10^{-8}	1.0×10^{-7}	5.1×10^{-11}	2.9×10^{-8}	1.7×10^{-7}	1.8×10^{-9}	8.5×10^{-11}
Advanced Boiling Water Reactor	7.3×10^{-4}	2.0×10^{-2}	5.8×10^{-3}	8.9×10^{-4}	2.7×10^{-2}	2.9×10^{-4}	1.4×10^{-5}
CE System 80+ Reactor	2.8×10^{-3}	2.0×10^{-2}	8.3×10^{-4}	4.5×10^{-4}	2.4×10^{-2}	2.6×10^{-4}	1.2×10^{-5}
[Text deleted.]							
AP600 Reactor	1.5×10^{-3}	1.7×10^{-2}	2.8×10^{-3}	6.9×10^{-4}	2.2×10^{-2}	2.4×10^{-4}	1.1×10^{-5}
RESAR-90 Reactor	2.4×10^{-3}	2.7×10^{-2}	1.2×10^{-3}	5.8×10^{-4}	3.2×10^{-2}	3.5×10^{-4}	1.6×10^{-5}

[a] Dose to the population within 80 km from natural background radiation in year 2030 is equal to 9,190 person-rem.

Source: HNUS 1996a.

M.2.5.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, five of the six areas have radioactive releases to the atmosphere from normal operation. Table M.2.5.1–1 presents the estimated annual atmospheric radioactive releases.

Table M.2.5.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Nevada Test Site (curies)

Isotope	Area 3	Area 5	Area 9	Area 12	Area 19
H-3	0	0.29	0	3.7	0
Kr-85	0	0	0	0	160
Pu-239	1.0×10^{-3}	0	7.5×10^{-4}	0	0

Source: NT DOE 1994b.

Tables M.2.5–3 and M.2.5–4, respectively, include the radiological impacts to the maximally exposed member of the public and offsite population within 80 km (50 mi). The MEI would receive an annual dose of 4.2×10^{-3} mrem. An estimated fatal cancer risk of 1.0×10^{-7} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 3.7×10^{-3} person-rem in 2030 (mid-life of operation). An estimated 9.3×10^{-5} fatal cancers could result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. There are no radioactive liquid releases to the offsite environment associated with No Action. Therefore, there are no resulting impacts.

Worker Doses and Health Effects. Based on measured values during the time period of 1989 to 1992 (*Twenty-Second Annual Report Radiation Exposures for DOE and DOE Contract Employees–1989* [DOE/EH-0286P]) and subsequent yearly dose reports), the annual average dose to a badged worker at NTS was calculated to be 5 mrem. It is projected that in 2005 and beyond, there would be 619 badged workers involved in No Action activities at NTS. The annual average dose to these workers was assumed to remain at 5 mrem; the annual total dose among all these workers would then equal 3 person-rem. From 50 years of operation, an estimated fatal cancer risk of 1.0×10^{-4} would result to the average worker and 0.060 fatal cancer could result among all workers.

M.2.5.2 Storage and Disposition

Radioactive Releases and Resulting Impacts to the Public. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the incremental impacts from the storage or disposition facilities to determine the impacts from total site operation. For example, to determine the radiological impact for the addition of an AP600 reactor at NTS, the doses from No Action facilities have to be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases from the facilities associated with the various alternative actions are given in Section M.2.3. Tables M.2.5–3 and M.2.5–4 include the radiological impacts by alternative facility. There are no radioactive liquid releases to the offsite environment associated with any alternative action.

The annual incremental doses associated with the different alternative facilities range from 2.7×10^{-9} to 0.034 mrem to the MEI and from 5.3×10^{-9} to 0.032 person-rem to the 80-km (50-mi) population in the year 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the incremental impacts from the storage or disposition facilities to determine the impacts from total site operation (refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.6 RADIOLOGICAL IMPACTS AT IDAHO NATIONAL ENGINEERING LABORATORY

This section presents the radiological impacts of various storage and disposition alternatives at INEL. Section M.2.6.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.6.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modelling, INEL was divided into nine separate areas which would release radioactivity in 2005. All release points in each area were aggregated into a single release point. Table M.2.6–1 presents the characteristics of each of the release points including location, release height, and minimum distance to and annual average dispersion to the site boundary in each of the 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For further clarification on the definition of the "maximum receptor" refer to Section M.2.2.2. For example, the dose resulting from releases from the Test Reactor Area, Argonne National Laboratory-West (ANL-W), Waste Experimental Reduction Facility/Power Burst Facility Area, and the other storage and disposition alternatives, has been determined for the maximum receptor from the Central Facilities Area. Figure M.2.6–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred to the site MEI) is then determined by the maximum dose to one of these maximum receptors. Table M.2.6–2 presents the direction, distance, and atmospheric dispersion from each release point to each of the maximum receptors. Annual radiological releases were assumed to remain constant during the full operational period.

The population and food stuffs distributions centered on each release area are provided in a Health Risk Data report, October 1996. The joint frequency distribution used for the dose assessment was based on the meteorological measurements for the year 1986 from the GRID III tower at the 10-m (33-ft) height and is contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables, and for the projected operational period in the text. Tables M.2.6–3 and M.2.6–4 include the radiological impact to the public from atmospheric releases for No Action and the storage and disposition alternatives.

Table M.2.6–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Idaho National Engineering Laboratory Boundary

Release Point[a]	SMC		TAN		TRA		ICPP		LWR Site	
Latitude	43°51'27.741"		43°50'56.339"		43°35'8.244"		43°34'16.091"		43°34'42.623"	
Longitude	-112°43'47.366"		-112°42'14.153"		-112°57'46.840"		-112°56'4.083"		-112°52'5.376"	
Release Height	Ground Level		51.4 m		76.2 m		76.2 m		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary									
Direction	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**
N	18,016	1.6×10^{-8}	18,938	5.2×10^{-9}	19,099	3.3×10^{-9}	20,722	3.1×10^{-9}	22,328	1.2×10^{-8}
NNE	16,399	3.7×10^{-8}	12,650	1.8×10^{-8}	21,737	6.8×10^{-9}	24,282	6.0×10^{-9}	44,886	9.8×10^{-9}
NE	13,055	1.2×10^{-7}	12,336	4.4×10^{-8}	42,901	7.3×10^{-9}	42,405	7.4×10^{-9}	37,705	2.9×10^{-8}
ENE	12,005	9.9×10^{-8}	9,884	3.4×10^{-8}	41,932	4.6×10^{-9}	39,577	4.9×10^{-9}	34,098	2.5×10^{-8}
E	11,726	4.0×10^{-8}	9,685	1.3×10^{-8}	26,374	2.9×10^{-9}	23,863	3.2×10^{-9}	19,377	2.0×10^{-8}
ESE	16,180	1.2×10^{-8}	15,770	3.9×10^{-9}	26,409	1.4×10^{-9}	24,074	1.5×10^{-9}	18,696	1.0×10^{-8}
SE	26,221	3.3×10^{-9}	23,757	1.3×10^{-9}	19,093	1.0×10^{-9}	16,409	1.2×10^{-9}	18,261	5.2×10^{-9}
SSE	35,151	3.2×10^{-9}	33,821	1.2×10^{-9}	15,967	1.6×10^{-9}	14,337	1.7×10^{-9}	14,690	1.0×10^{-8}
S	35,319	9.6×10^{-9}	33,731	3.8×10^{-9}	15,538	5.2×10^{-9}	13,952	5.8×10^{-9}	14,635	3.1×10^{-8}
SSW	46,586	9.7×10^{-9}	44,899	4.5×10^{-9}	15,753	1.0×10^{-8}	14,144	1.1×10^{-8}	15,028	4.3×10^{-8}
SW	30,060	1.8×10^{-8}	34,045	7.6×10^{-9}	18,299	1.2×10^{-8}	16,442	1.3×10^{-8}	17,459	3.7×10^{-8}
WSW	12,107	2.4×10^{-8}	14,260	6.8×10^{-9}	18,988	3.3×10^{-9}	21,409	2.9×10^{-9}	25,439	8.9×10^{-9}
W	11,779	3.4×10^{-8}	13,873	9.9×10^{-9}	17,014	5.2×10^{-9}	20,752	4.2×10^{-9}	24,305	1.3×10^{-8}
WNW	9,215	1.4×10^{-8}	11,510	3.5×10^{-9}	12,184	2.2×10^{-9}	14,992	1.8×10^{-9}	17,919	5.7×10^{-9}
NW	10,005	2.0×10^{-8}	12,462	4.4×10^{-9}	11,503	2.9×10^{-9}	14,283	2.3×10^{-9}	17,908	9.2×10^{-9}
NNW	14,481	1.3×10^{-8}	18,035	3.4×10^{-9}	12,204	3.4×10^{-9}	15,365	2.7×10^{-9}	20,732	8.2×10^{-9}

Table M.2.6–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Idaho National Engineering Laboratory Boundary —Continued

Release Point[a]	WERF		CFA		RWMC		ANL-W	
Latitude	43°33'3.443"		43°32'4.386"		43°29'58.551"		43°35'41.733"	
Longitude	-112°51'31.071"		-112°56'10.073"		-113°2'13.843"		-112°39'18.744"	
Release Height	24.4 m		Ground Level		Ground Level		42.7 m	
Distance and Atmospheric Dispersion at Site Boundary								
Direction	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**
N	25,458	$6.7x10^{-9}$	24,783	$1.1x10^{-8}$	17,201	$1.7x10^{-8}$	32,639	$8.3x10^{-9}$
NNE	41,139	$7.5x10^{-9}$	40,101	$1.1x10^{-8}$	29,087	$1.7x10^{-8}$	24,645	$1.4x10^{-8}$
NE	39,204	$1.9x10^{-8}$	45,052	$2.3x10^{-8}$	53,829	$1.8x10^{-8}$	19,642	$1.6x10^{-8}$
ENE	32,888	$1.6x10^{-8}$	39,302	$2.0x10^{-8}$	47,686	$1.6x10^{-8}$	16,056	$1.5x10^{-8}$
E	17,582	$1.4x10^{-8}$	23,842	$1.5x10^{-8}$	32,039	$1.0x10^{-8}$	14,469	$9.4x10^{-9}$
ESE	17,857	$6.7x10^{-9}$	18,765	$1.0x10^{-8}$	11,265	$2.0x10^{-8}$	9,005	$1.5x10^{-8}$
SE	14,508	$4.5x10^{-9}$	11,856	$9.4x10^{-9}$	7,293	$1.9x10^{-8}$	5,862	$2.6x10^{-8}$
SSE	11,541	$8.4x10^{-9}$	10,161	$1.7x10^{-8}$	6,090	$3.5x10^{-8}$	5,518	$5.5x10^{-8}$
S	11,539	$2.6x10^{-8}$	9,886	$5.3x10^{-8}$	5,924	$1.1x10^{-7}$	5,571	$7.3x10^{-8}$
SSW	11,937	$3.8x10^{-8}$	10,021	$7.5x10^{-8}$	6,003	$1.6x10^{-7}$	17,065	$2.5x10^{-8}$
SW	13,872	$3.4x10^{-8}$	11,653	$6.4x10^{-8}$	6,992	$1.3x10^{-7}$	19,886	$2.1x10^{-8}$
WSW	20,227	$7.9x10^{-9}$	16,966	$1.5x10^{-8}$	10,193	$3.0x10^{-8}$	28,926	$1.1x10^{-8}$
W	26,937	$7.5x10^{-9}$	20,726	$1.6x10^{-8}$	12,661	$3.1x10^{-8}$	35,298	$6.1x10^{-9}$
WNW	21,124	$3.1x10^{-9}$	19,192	$5.2x10^{-9}$	12,803	$8.9x10^{-9}$	32,525	$5.0x10^{-9}$
NW	20,318	$4.9x10^{-9}$	17,203	$9.7x10^{-9}$	14,757	$1.2x10^{-8}$	27,828	$6.4x10^{-9}$
NNW	23,853	$4.4x10^{-9}$	17,397	$1.0x10^{-8}$	16,111	$1.1x10^{-8}$	31,167	$8.5x10^{-9}$

[a] See Figure M.2.6–1 for location of release points.

Note: TAN=Test Area North; TRA=Test Reactor Area; WERF=Waste Experimental Reduction Area.

Source: HNUS 1996a.

Table M.2.6–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Idaho National Engineering Laboratory Site Boundary

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: SMC			
SMC and TAN	NE	14,481	$1.1x10^{-7}$
TRA	SSW	53,888	$8.1x10^{-9}$
ICPP	SSW	52,249	$8.4x10^{-9}$
LWR Site	SSW	47,838	$9.4x10^{-9}$
WERF	SSW	47,497	$9.5x10^{-9}$
CFA	SSW	49,319	$9.0x10^{-9}$
RWMC	SSW	52,487	$8.3x10^{-9}$
ANL-W	S	35,376	$9.6x10^{-9}$
Release Point: TAN			
SMC and TAN	NE	12,337	$4.4x10^{-8}$
TRA	SW	54,224	$4.4x10^{-9}$
ICPP	SSW	52,464	$3.8x10^{-9}$
LWR Site	SSW	47,566	$4.2x10^{-9}$
WERF	SSW	47,165	$4.3x10^{-9}$
CFA	SSW	49,252	$4.1x10^{-9}$
RWMC	SSW	52,722	$3.8x10^{-9}$
ANL-W	S	34,503	$3.7x10^{-9}$
Release Point: TRA			
SMC and TAN	NE	48,269	$6.4x10^{-9}$
TRA	SW	18,299	$1.2x10^{-8}$
ICPP	SSW	16,796	$9.4x10^{-9}$
LWR Site	SSE	16,393	$1.5x10^{-9}$
WERF	SSE	16,850	$1.5x10^{-9}$
CFA	S	15,549	$5.2x10^{-9}$
RWMC	SSW	16,992	$9.3x10^{-9}$
ANL-W	E	16,415	$2.9x10^{-9}$
Release Point: ICPP			
SMC and TAN	NE	48,292	$6.4x10^{-9}$
TRA	SW	18,395	$1.2x10^{-8}$
ICPP	SW	16,443	$1.3x10^{-8}$
LWR Site	S	14,251	$5.7x10^{-9}$
WERF	SSE	14,570	$1.7x10^{-9}$
CFA	S	14,059	$5.8x10^{-9}$
RWMC	SW	16,712	$1.3x10^{-8}$
ANL-W	E	23,906	$3.2x10^{-9}$
Release Point: LWR Site			
SMC and TAN	NNE	44,887	$9.8x10^{-9}$
TRA	SW	22,811	$2.6x10^{-8}$
ICPP	SW	20,426	$3.0x10^{-8}$
LWR Site	SSW	15,029	$4.3x10^{-8}$
WERF	S	14,873	$3.0x10^{-8}$

Table M.2.6–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Idaho National Engineering Laboratory Site Boundary—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
CFA	SSW	16,430	3.8×10^{-8}
RWMC	SW	20,771	2.9×10^{-8}
ANL-W	ESE	18,736	1.0×10^{-8}
Release Point: WERF			
SMC and TAN	NNE	47,288	6.3×10^{-9}
TRA	WSW	21,626	7.3×10^{-9}
ICPP	SW	18,954	2.3×10^{-8}
LWR Site	SSW	12,217	3.6×10^{-8}
WERF	SSW	11,938	3.8×10^{-8}
CFA	SW	14,170	3.3×10^{-8}
RWMC	SW	19,347	2.2×10^{-8}
ANL-W	E	17,626	1.4×10^{-8}
Release Point: CFA			
SMC and TAN	NNE	51,824	8.2×10^{-9}
TRA	SW	15,468	4.3×10^{-8}
ICPP	SW	13,109	5.4×10^{-8}
LWR Site	SSE	10,331	1.6×10^{-8}
WERF	SSE	10,777	1.5×10^{-8}
CFA	SSW	10,021	7.5×10^{-8}
RWMC	SW	13,442	5.2×10^{-8}
ANL-W	E	23,916	1.5×10^{-8}
Release Point: RWMC			
SMC and TAN	NE	59,528	1.6×10^{-8}
TRA	SW	7,019	1.3×10^{-7}
ICPP	S	5,943	1.1×10^{-7}
LWR Site	ESE	12,605	1.7×10^{-8}
WERF	ESE	13,761	1.5×10^{-8}
CFA	SE	8,791	1.4×10^{-8}
RWMC	SSW	6,004	1.6×10^{-7}
ANL-W	E	32,468	1.0×10^{-8}
Release Point: ANL-W			
SMC and TAN	N	38,094	6.8×10^{-9}
TRA	WSW	38,408	7.9×10^{-9}
ICPP	WSW	35,484	8.7×10^{-9}
LWR Site	SW	25,870	1.5×10^{-8}
WERF	SW	24,903	1.5×10^{-8}
CFA	WSW	29,537	1.1×10^{-8}
RWMC	WSW	35,923	8.6×10^{-9}
ANL-W	S	5,572	7.3×10^{-8}

Note: WERF=Waste Experimental Reduction Facility; TAN=Test Area North; TRA=Test Reactor Area.
Source: HNUS 1996a.

Table M.2.6–3. Doses and Resulting Health Effects to the Maximally Exposed Individual at Idaho National Engineering Laboratory From Atmospheric Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	2.8×10^{-4}	1.5×10^{-2}	2.2×10^{-3}	2.9×10^{-5}	1.8×10^{-2}[b]	5.2×10^{-3}	8.9×10^{-9}
Upgrade Storage	5.1×10^{-7}	8.8×10^{-10}	1.9×10^{-16}	4.0×10^{-13}	5.1×10^{-7}	1.5×10^{-7}	2.6×10^{-13}
Consolidated Storage Facility	1.6×10^{-6}	2.8×10^{-9}	6.1×10^{-16}	1.3×10^{-12}	1.6×10^{-6}	4.7×10^{-7}	8.0×10^{-13}
Collocated Storage Facility	1.6×10^{-6}	2.8×10^{-9}	6.5×10^{-16}	1.9×10^{-12}	1.6×10^{-6}	4.7×10^{-7}	8.0×10^{-13}
Pit Disassembly/ Conversion Facility	1.8×10^{-4}	4.0×10^{-6}	1.1×10^{-12}	1.6×10^{-9}	1.8×10^{-4}	5.3×10^{-5}	9.0×10^{-11}
Pu Conversion Facility	1.2×10^{-4}	2.2×10^{-7}	5.0×10^{-14}	1.0×10^{-10}	1.2×10^{-4}	3.6×10^{-5}	6.0×10^{-11}
MOX Fuel Fabrication Facility	8.8×10^{-5}	1.5×10^{-7}	3.3×10^{-14}	1.6×10^{-10}	8.8×10^{-5}	2.6×10^{-5}	4.4×10^{-11}
Ceramic Immobilization Facility (Immobilized Disposition)	2.0×10^{-8}	3.6×10^{-11}	8.1×10^{-18}	1.6×10^{-14}	2.0×10^{-8}	5.9×10^{-9}	1.0×10^{-14}
Deep Borehole Complex (Direct Disposition)	3.3×10^{-9}	4.9×10^{-11}	1.3×10^{-17}	1.9×10^{-14}	3.4×10^{-9}	1.0×10^{-9}	1.7×10^{-15}
Deep Borehole Complex (Immobilized Disposition)	4.1×10^{-9}	7.2×10^{-11}	1.9×10^{-17}	2.9×10^{-14}	4.2×10^{-9}	1.2×10^{-9}	2.1×10^{-15}
Vitrification Facility	8.2×10^{-6}	5.5×10^{-7}	1.6×10^{-10}	9.0×10^{-8}	8.9×10^{-6}	2.6×10^{-6}	4.4×10^{-12}
Ceramic Immobilization Facility (Ceramic Immobilization)	2.3×10^{-8}	1.1×10^{-7}	3.2×10^{-11}	1.7×10^{-8}	1.5×10^{-7}	4.4×10^{-8}	7.5×10^{-14}
Advanced Boiling Water Reactor	1.2×10^{-3}	6.2×10^{-2}	1.3×10^{-2}	1.4×10^{-3}	7.8×10^{-2}	2.3×10^{-2}	3.9×10^{-8}
CE System 80+ Reactor	1.9×10^{-3}	3.6×10^{-2}	7.2×10^{-4}	3.0×10^{-4}	3.8×10^{-2}	1.1×10^{-2}	1.9×10^{-8}
[Text deleted.]							
AP600 Reactor	1.0×10^{-3}	2.9×10^{-2}	2.2×10^{-3}	4.5×10^{-4}	3.3×10^{-2}	9.8×10^{-3}	1.7×10^{-8}
RESAR-90 Reactor	1.6×10^{-3}	4.3×10^{-2}	9.0×10^{-4}	3.8×10^{-4}	4.6×10^{-2}	1.4×10^{-2}	2.3×10^{-8}

[a] Average individual annual natural background radiation is equal to 338 mrem.

[b] The storage facility contributes 1.4×10^{-5} mrem/year.

[Text deleted.]

Source: HNUS 1996a.

Table M.2.6–4. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Idaho National Engineering Laboratory From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	2.9×10^{-3}	2.4	2.1×10^{-2}	3.0×10^{-4}	2.4[b]	2.7×10^{-3}	1.2×10^{-3}
Upgrade Storage	3.1×10^{-6}	1.5×10^{-7}	1.2×10^{-15}	2.5×10^{-12}	3.2×10^{-6}	3.5×10^{-9}	1.6×10^{-9}
Consolidated Storage Facility	1.7×10^{-5}	9.1×10^{-7}	6.5×10^{-15}	1.4×10^{-11}	1.8×10^{-5}	2.0×10^{-8}	9.0×10^{-9}
Collocated Storage Facilities	1.7×10^{-5}	9.2×10^{-7}	6.9×10^{-15}	2.1×10^{-11}	1.8×10^{-5}	2.0×10^{-8}	9.0×10^{-9}
Pit Disassembly/ Conversion Facility	1.9×10^{-3}	1.3×10^{-3}	1.1×10^{-11}	1.6×10^{-8}	3.2×10^{-3}	3.5×10^{-6}	1.6×10^{-6}
Pu Conversion Facility	8.6×10^{-4}	3.1×10^{-4}	1.9×10^{-12}	3.1×10^{-9}	1.2×10^{-3}	1.3×10^{-6}	6.0×10^{-7}
MOX Fuel Fabrication Facility	9.2×10^{-4}	4.9×10^{-5}	3.5×10^{-13}	1.7×10^{-9}	9.7×10^{-4}	1.1×10^{-6}	4.9×10^{-7}
Ceramic Immobilization Facility (Immobilized Disposition)	2.2×10^{-7}	1.2×10^{-8}	8.4×10^{-17}	1.7×10^{-13}	2.3×10^{-7}	2.5×10^{-10}	1.2×10^{-10}
Deep Borehole Complex (Direct Disposition)	3.5×10^{-8}	1.6×10^{-8}	1.3×10^{-16}	2.0×10^{-13}	5.1×10^{-8}	5.6×10^{-11}	2.6×10^{-11}
Deep Borehole Complex (Immobilized Disposition)	4.4×10^{-8}	2.3×10^{-8}	2.0×10^{-16}	3.0×10^{-13}	6.7×10^{-8}	7.4×10^{-11}	3.4×10^{-11}
Vitrification Facility	8.6×10^{-5}	7.1×10^{-5}	1.7×10^{-9}	9.0×10^{-7}	1.6×10^{-4}	1.8×10^{-7}	8.0×10^{-8}
Ceramic Immobilization Facility (Ceramic Immobilization)	2.4×10^{-7}	1.3×10^{-5}	3.3×10^{-10}	1.9×10^{-7}	1.4×10^{-5}	1.5×10^{-8}	7.0×10^{-9}
Advanced Boiling Water Reactor	1.0×10^{-2}	13	7.6×10^{-2}	1.2×10^{-2}	14	1.5×10^{-2}	6.8×10^{-3}
CE System 80+ Reactor	2.1×10^{-2}	8.6	5.4×10^{-3}	3.4×10^{-3}	8.6	9.5×10^{-3}	4.3×10^{-3}
[Text deleted.]							
AP600 Reactor	1.1×10^{-2}	6.9	1.9×10^{-2}	5.1×10^{-3}	6.9	7.6×10^{-3}	3.5×10^{-3}
RESAR-90 Reactor	1.8×10^{-2}	9.6	8.2×10^{-3}	4.3×10^{-3}	9.6	1.1×10^{-2}	4.8×10^{-3}

[a] Total dose to the population within 80 km from natural background radiation in the year 2030 is equal to 90,800 person-rem.

[b] The storage facility contributes 7.6x10-5 person-rem/year.

[Text deleted.]

Source: HNUS 1996a.

M.2.6.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, eight of the nine areas have radioactive releases to the atmosphere from normal operation. Table M.2.6.1–1 presents the estimated annual atmospheric radioactive releases.

Tables M.2.6–3 and M.2.6–4 include the radiological impacts to the MEI and to the offsite population within 80 km (50 mi), respectively. The maximally exposed individual would receive an annual dose of 0.018 mrem. An estimated fatal cancer risk of 4.4×10^{-7} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 2.4 person-rem in 2030 (mid-life of operation). An estimated 0.061 fatal cancers could result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. There are no radioactive liquid releases to the offsite environment associated with No Action. Therefore, there are no resulting impacts.

Worker Doses and Health Effects. Based on measured values during the time period of 1989 to 1992 (*Twenty-Second Annual Report Radiation Exposures for DOE and DOE Contractor Employees–1989* [DOE/EH-0286P] and subsequent yearly data reports), the annual average radiation dose to a badged worker at INEL was calculated to be 30 mrem. It is projected that in 2005 and beyond, there would be 7,337 badged workers involved in No Action activities at INEL. The annual average radiation dose to these workers is assumed to remain at 30 mrem; the annual total radiation dose among all these workers would then equal 220 person-rem. From 50 years of operation, an estimated fatal cancer risk of 6.0×10^{-4} would result to the average worker and 4.4 fatal cancers could result among all workers.

Table M.2.6.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Idaho National Engineering Laboratory (curies)

	SMC	TAN		TRA		ICPP		WERF		CFA	RWMC	ANL-W[a]	
Isotope	All Releases	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	All Releases	All Releases	Monitored/ Non-monitored	Diffuse Area
Ag-110m	0	0	0	0	0	5.1×10^{-12}	0	0	0	0	0	0	0
Am-241	0	0	0	0	5.8×10^{-7}	2.4×10^{-11}	2.2×10^{-9}	0	0	0	2.0×10^{-6}	0	0
Am-243	0	0	0	0	0	2.4×10^{-13}	0	0	0	0	0	0	0
Ar-41	0	0	0	1.3×10^{3}	0	0	0	0	0	0	0	17	0
Ba-139	0	0	0	5.4×10^{-2}	0	0	0	0	0	0	0	0	0
Ba-140	0	0	0	6.2×10^{-6}	0	0	0	0	0	0	0	2.7×10^{-3}	0
C-14	0	0	0	0	0	9.6×10^{-3}	0	0	0	0	0	0	0
Cd-113m	0	0	0	0	0	8.6×10^{-14}	0	0	0	0	0	0	0
Ce-141	0	0	0	0	0	2.5×10^{-12}	0	0	0	0	0	0	0
Ce-144	0	0	0	0	0	3.8×10^{-6}	9.2×10^{-9}	0	0	0	0	0	0
Cm-244	0	0	0	0	3.0×10^{-5}	0	0	0	0	0	0	0	0
Co-57	0	0	0	0	0	7.8×10^{-8}	0	0	0	0	0	0	0
Co-58	0	0	0	8.0×10^{-7}	0	2.4×10^{-7}	0	0	0	0	0	8.8×10^{-6}	0
Co-60	0	3.5×10^{-7}	5.7×10^{-7}	2.4×10^{-4}	3.8×10^{-4}	9.6×10^{-6}	4.5×10^{-9}	0	2.3×10^{-6}	2.0×10^{-6}	7.8×10^{-10}	1.6×10^{-5}	0
Cr-51	0	0	0	3.8×10^{-3}	7.1×10^{-7}	5.6×10^{-15}	0	0	0	0	0	0	0
Cs-134	0	0	2.9×10^{-10}	0	5.0×10^{-7}	8.8×10^{-5}	2.6×10^{-8}	0	5.6×10^{-7}	5.6×10^{-8}	0	1.5×10^{-4}	0
Cs-137	0	1.3×10^{-6}	2.7×10^{-6}	6.1×10^{-6}	8.7×10^{-4}	8.1×10^{-3}	7.6×10^{-6}	0	4.7×10^{-5}	9.0×10^{-5}	1.4×10^{-5}	8.2×10^{-4}	0
Cs-138	0	0	0	0.69	0	0	0	0	0	0	0	0	0
Eu-152	0	0	0	0	7.9×10^{-7}	8.7×10^{-5}	1.1×10^{-6}	0	0	4.7×10^{-8}	0	0	0
Eu-154	0	0	4.1×10^{-10}	0	3.7×10^{-7}	6.0×10^{-5}	0	0	0	9.1×10^{-8}	0	1.6×10^{-5}	0
Eu-155	0	0	0	0	7.1×10^{-8}	8.7×10^{-6}	0	0	0	2.2×10^{-8}	0	9.3×10^{-4}	0
Fe-55	0	0	0	0	0	4.5×10^{-9}	0	0	0	0	0	0	0
Hg-203	0	0	0	8.8×10^{-5}	0	0	0	0	0	4.7×10^{-9}	0	0	0
H-3	0	0	0	11	120	67	8.9×10^{-9}	0	0	4.4	0	34	7.9×10^{-2}
I-129	0	0	0	0	0	9.8×10^{-2}	3.8×10^{-8}	0	0	0	0	0	0
I-131	0	0	0	1.1×10^{-4}	0	0	0	0	0	0	0	0	0
I-132	0	0	0	1.1×10^{-3}	0	0	0	0	0	0	0	0	0
I-133	0	0	0	4.3×10^{-4}	0	0	0	0	0	0	0	0	0

Table M.2.6.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Idaho National Engineering Laboratory (curies)—Continued

	SMC	TAN		TRA		ICPP		WERF		CFA	RWMC	ANL-W[a]	
Isotope	All Releases	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	All Releases	All Releases	Monitored/ Non-monitored	Diffuse Area
Kr-85	0	0	0	0	0	0	0	0	0	0	0	70	0
Kr-85m	0	0	0	8.0	0	0	0	0	0	0	0	44	0
Kr-87	0	0	0	25	0	0	0	0	0	0	0	38	0
Kr-88	0	0	0	24	0	0	0	0	0	0	0	55	0
La-140	0	0	0	1.2×10^{-4}	0	0	0	0	0	0	0	1.5×10^{-5}	0
Mn-54	0	0	0	0	0	5.2×10^{-11}	0	0	0	0	0	5.0×10^{-5}	0
Na-22	0	0	0	0	0	0	0	0	0	0	0	3.8×10^{-5}	0
Na-24	0	0	0	5.2×10^{-3}	0	0	0	0	0	0	0	1.0×10^{-7}	0
Nb-94	0	0	0	0	0	1.1×10^{-15}	0	0	0	0	0	0	0
Nb-95	0	0	0	0	0	4.8×10^{-7}	3.1×10^{-8}	0	0	0	0	0	0
Nb-95m	0	0	0	0	0	3.4×10^{-15}	0	0	0	0	0	0	0
Ni-63	0	0	0	0	0	4.3×10^{-15}	0	0	0	0	0	0	0
Np-239	0	0	0	0	0	3.8×10^{-16}	1.6×10^{-8}	0	0	0	0	0	0
Pa-234	2.2×10^{-8}	0	0	0	0	2.3×10^{-15}	0	0	0	0	0	0	0
Pm-147	0	0	0	0	0	2.5×10^{-6}	0	0	0	0	0	0	0
Pr-144	0	0	0	0	0	4.5×10^{-6}	0	0	0	0	0	0	0
Pr-144m	0	0	0	0	0	2.6×10^{-9}	0	0	0	0	0	0	0
Pu-238	0	0	2.1×10^{-9}	0	8.2×10^{-7}	8.5×10^{-8}	1.7×10^{-8}	0	1.4×10^{-10}	0	0	0	0
Pu-239	0	6.2×10^{-8}	0	8.1×10^{-7}	3.1×10^{-6}	1.4×10^{-6}	0	8.5×10^{-8}	1.9×10^{-10}	1.8×10^{-7}	1.2×10^{-6}	1.6×10^{-6}	0
Pu-240	0	0	1.9×10^{-9}	0	0	2.3×10^{-7}	0	0	0	0	0	0	0
Pu-241	0	0	0	0	0	5.1×10^{-6}	0	0	0	0	0	0	0
Rb-88	0	0	0	0.52	0	0	0	0	0	0	0	1.3×10^{-3}	0
Rb-89	0	0	0	0.73	0	0	0	0	0	0	0	0	0
Ru-106	0	0	0	0	0	1.0×10^{-3}	7.2×10^{-8}	0	0	0	0	0	0
Sb-125	0	0	0	0	0	9.8×10^{-5}	2.4×10^{-7}	0	0	2.8×10^{-8}	0	0	0
Sn-199m	0	0	0	0	0	2.4×10^{-8}	0.0	0	0	0	0	0	0
Sr-90	0	2.9×10^{-7}	1.9×10^{-7}	3.6×10^{-4}	8.6×10^{-5}	1.4×10^{-3}	9.5×10^{-9}	4.1×10^{-8}	6.8×10^{-6}	7.8×10^{-7}	3.0×10^{-8}	2.6×10^{-3}	0
Tc-99m	0	0	0	2.2×10^{-3}	0	2.2×10^{-13}	0	0	0	0	0	0	0

Table M.2.6.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Idaho National Engineering Laboratory (curies)—Continued

	SMC	TAN		TRA		ICPP		WERF		CFA	RWMC	ANL-W[a]	
Isotope	All Releases	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	Monitored/ Non-monitored	Diffuse Area	All Releases	All Releases	Monitored/ Non-monitored	Diffuse Area
Th-228	0	0	0	0	2.0×10^{-7}	0	0	0	0	0	0	0	0
Th-230	0	0	0	0	1.0×10^{-7}	0	0	0	0	0	0	0	0
Th-231	0	0	0	0	0	5.6×10^{-12}	0	0	0	0	0	0	0
Th-232	0	0	0	0	9.5×10^{-9}	0.0	0	0	0	0	0	0	0
Th-234	7.7×10^{-6}	0	0	0	0	7.8×10^{-13}	0	0	0	0	0	0	0
U-232	0	0	0	0	1.7×10^{-7}	0.0	0	0	0	0	0	0	0
U-233	0	0	0	0	0	1.2×10^{-14}	0	0	0	0	0	0	0
U-234	1.0×10^{-6}	0	5.0×10^{-8}	0	1.9×10^{-5}	1.4×10^{-6}	2.4×10^{-8}	0	2.4×10^{-8}	0	0	0	0
U-235	0	0	1.8×10^{-9}	0	0	5.8×10^{-8}	0	0	1.2×10^{-7}	1.4×10^{-10}	9.5×10^{-9}	3.7×10^{-9}	0
U-238	7.7×10^{-6}	0	3.8×10^{-8}	0	1.2×10^{-5}	4.8×10^{-9}	0	0	6.1×10^{-9}	0	0	5.3×10^{-10}	0
Xe-133	0	0	0	4.2	0	2.7×10^{-9}	0	0	0	0	0	490	0
Xe-135	0	0	0	28	0	0	0	0	0	0	0	310	0
Xe-135m	0	0	0	14	0	0	0	0	0	0	0	11	0
Xe-138	0	0	0	71	0	0	0	0	0	0	0	22	0
Y-90	0	0	0	0.0	0	2.9×10^{-4}	9.5×10^{-9}	0	0	0	0	0	0
Y-91m	0	0	0	1.6×10^{-3}	0	1.7×10^{-10}	0	0	0	0	0	0	0
Zn-65	0	0	0	5.7×10^{-8}	5.7×10^{-8}	0	0	4.8×10^{-7}	0	0	0	0	0
Zr-93	0	0	0	0.0	0.0	2.2×10^{-15}	0	0	0	0	0	0	0
Zr-95	0	0	0	0.0	0.0	4.1×10^{-6}	0	0	0	0	0	0	0

[a] ANL-W reported that releases from the no action storage are not measurable. For calculation purposes, it was assumed that all the Pu released from ANL-W in 1993 was released from Pu storage. This is very conservative since EBR-II, a Pu-fueled reactor, was in operation in 1993. In October 1995, the EBR-II was defueled and is no longer in operation.

Note: TAN=Test Area North; TRA=Test Reactor Area; WERF=Waste Experimental Reduction Facility.

Source: IN DOE 1994c.

M.2.6.2 Storage and Disposition

Radioactive Releases and Resulting Impacts to the Public. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the changes in impacts from the storage or disposition facilities to determine the impacts from total site operation. For example, to determine the radiological impact for the addition of an AP600 reactor at INEL, the doses from No Action facilities have to be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases from the facilities associated with the various alternative actions are given in Section M.2.3. Tables M.2.6–3 and M.2.6–4 include the radiological impacts by alternative facility. There are no radioactive liquid releases to the offsite environment associated with any alternative action.

The annual incremental doses associated with the different alternative facilities range from 3.4×10^{-9} to 0.078 mrem to the MEI and from 5.1×10^{-8} to 9.6 person-rem to the 80-km (50-mi) population in 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the incremental impacts from the storage or disposition facilities to determine the impacts from total site operations (refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.7 RADIOLOGICAL IMPACTS AT PANTEX PLANT

This section presents the radiological impacts of the various storage and disposition alternatives at Pantex. Section M.2.7.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.7.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modeling, Pantex was divided into six areas which would release radioactivity in 2005. All release points in each area were aggregated into a single release point. Table M.2.7–1 presents the characteristics of each of the release points including location, release height, and minimum distance and annual average dispersion to the site boundary in each of 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For further clarification on the definition of "maximum receptor," refer to Section M.2.2.2. For example, the dose resulting from releases from Building 12-44 Cell 1 and the other storage and disposition alternatives, has been determined from the maximum receptor from the Burning Ground. Figure M.2.7–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred to the site MEI) is then determined by the maximum dose to one of these maximum receptors. Table M.2.7–2 presents the distance, direction, and atmospheric dispersion from each release point to each of the maximum receptors. Annual radiological releases were assumed to remain constant during the full operational period.

Descriptions of population and food stuff distributions centered on each release area are provided in a Health Risk Data report, October 1996. The joint frequency distribution used for the dose assessment was based on the meteorological measurements for 1989 from the National Weather Service at the 10-m (33-ft) height and is contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables and for the projected operational period in the text. Tables M.2.7–3 and M.2.7–4 include the radiological impacts to the public from atmospheric releases for the No Action and the storage and disposition alternatives.

Table M.2.7–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Pantex Plant Boundary

Release Point[a]	Bldg. 12-44 Cell 1	HE Burning Ground	Between Zones 11 and 12	Strategic Reserve	Immobilization Facility	LWR Site
Latitude	35° 18' 24.087"	35° 20' 40.781"	35° 18' 46.315"	35° 18' 22.415"	35° 19' 46.714"	35° 20' 25.520"
Longitude	-101° 33' 25.592"	-101° 35' 4.249"	-101° 33' 53.239"	-101° 33' 36.363"	-101° 34' 14.606"	-101° 36' 14.568"
Release Height	10.0 m	10.0 m	Ground Level	Ground Level	Ground Level	Ground Level

	Distance and Atmospheric Dispersion at Site Boundary											
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	5,176	$1.6x10^{-7}$	931	$1.7x10^{-6}$	4,482	$2.1x10^{-7}$	5,224	$1.7x10^{-7}$	2,614	$4.8x10^{-7}$	1,380	$1.4x10^{-6}$
NNE	2,790	$2.4x10^{-7}$	950	$1.0x10^{-6}$	4,095	$1.5x10^{-7}$	3,315	$2.1x10^{-7}$	2,660	$2.9x10^{-7}$	1,406	$8.1x10^{-7}$
NE	1,831	$3.6x10^{-7}$	1,127	$7.0x10^{-7}$	2,691	$2.3x10^{-7}$	2,168	$3.3x10^{-7}$	3,141	$1.8x10^{-7}$	1,659	$5.0x10^{-7}$
ENE	1,534	$2.8x10^{-7}$	1,665	$2.5x10^{-7}$	2,247	$1.9x10^{-7}$	1,811	$2.7x10^{-7}$	2,783	$1.3x10^{-7}$	2,444	$1.6x10^{-7}$
E	1,490	$3.2x10^{-7}$	3,963	$8.1x10^{-8}$	2,185	$2.2x10^{-7}$	1,762	$3.1x10^{-7}$	2,716	$1.6x10^{-7}$	5,741	$5.2x10^{-8}$
ESE	1,516	$2.1x10^{-7}$	4,028	$5.4x10^{-8}$	2,225	$1.5x10^{-7}$	1,792	$2.1x10^{-7}$	2,761	$1.0x10^{-7}$	5,837	$3.5x10^{-8}$
SE	1,781	$2.1x10^{-7}$	4,719	$5.6x10^{-8}$	2,604	$1.5x10^{-7}$	2,091	$2.1x10^{-7}$	3,224	$1.1x10^{-7}$	6,827	$3.6x10^{-8}$
SSE	2,577	$9.5x10^{-8}$	6,942	$2.4x10^{-8}$	3,465	$7.1x10^{-8}$	2,625	$1.1x10^{-7}$	4,776	$4.4x10^{-8}$	7,587	$2.3x10^{-8}$
S	2,607	$1.8x10^{-7}$	7,473	$4.2x10^{-8}$	3,505	$1.3x10^{-7}$	2,651	$2.1x10^{-7}$	5,454	$6.9x10^{-8}$	7,270	$4.6x10^{-8}$
SSW	3,001	$9.1x10^{-8}$	5,659	$3.7x10^{-8}$	4,037	$6.6x10^{-8}$	3,055	$1.0x10^{-7}$	6,285	$3.4x10^{-8}$	2,333	$1.5x10^{-7}$
SW	4,290	$4.8x10^{-8}$	3,696	$5.9x10^{-8}$	5,768	$3.5x10^{-8}$	4,379	$5.1x10^{-8}$	5,225	$4.0x10^{-8}$	1,513	$2.7x10^{-7}$
WSW	5,643	$4.8x10^{-8}$	3,083	$1.1x10^{-7}$	4,925	$6.4x10^{-8}$	5,366	$5.6x10^{-8}$	4,368	$7.6x10^{-8}$	1,257	$5.3x10^{-7}$
W	5,495	$5.0x10^{-8}$	2,999	$1.1x10^{-7}$	4,795	$6.5x10^{-8}$	5,223	$5.8x10^{-8}$	4,254	$7.8x10^{-8}$	1,223	$5.5x10^{-7}$
WNW	5,577	$3.8x10^{-8}$	1,730	$1.9x10^{-7}$	4,873	$5.0x10^{-8}$	5,301	$4.4x10^{-8}$	4,320	$6.0x10^{-8}$	1,249	$4.2x10^{-7}$
NW	6,304	$5.1x10^{-8}$	1,142	$5.3x10^{-7}$	5,454	$6.7x10^{-8}$	6,177	$5.6x10^{-8}$	3,199	$1.5x10^{-7}$	1,462	$5.1x10^{-7}$
NNW	5,293	$6.6x10^{-8}$	955	$6.9x10^{-7}$	4,585	$8.7x10^{-8}$	5,346	$7.0x10^{-8}$	2,681	$1.9x10^{-7}$	1,417	$5.4x10^{-7}$

[a] See Figure M.2.7–1 for location of release points.

Source: HNUS 1996a.

Table M.2.7–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Pantex Plant Boundary

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: Bldg. 12-44 Cell 1			
Bldg. 12-44 Cell 1	NE	1,831	$3.6x10^{-7}$
HE Burning Ground	NNW	5,728	$5.9x10^{-8}$
Between Zone 11 and 12	NE	2,707	$2.0x10^{-7}$
Strategic Reserve	NE	1,922	$3.3x10^{-7}$
Immobilization Facility	NNW	5,315	$6.5x10^{-8}$
LWR Site	NW	6,695	$4.7x10^{-8}$
Release Point: HE Burning Ground			
Bldg. 12-44 Cell 1	SE	5,069	$5.0x10^{-8}$
HE Burning Ground	N	932	$1.7x10^{-6}$
Between Zone 11 and 12	ESE	4,424	4.7x10-8
Strategic Reserve	SE	4,977	$5.2x10^{-8}$
Immobilization Facility	NE	1,544	$4.5x10^{-7}$
LWR Site	WNW	2,032	$1.5x10^{-7}$
Release Point: Between Zone 11 and 12			
Bldg. 12-44 Cell 1	E	2,218	$2.2x10^{-7}$
HE Burning Ground	NNW	4,817	$8.1x10^{-8}$
Between Zone 11 and 12	NE	2,692	2.3x10-7
Strategic Reserve	ENE	2,248	$1.9x10^{-7}$
Immobilization Facility	N	4,512	$2.1x10^{-7}$
LWR Site	NW	5,722	$6.3x10^{-8}$
Release Point: Strategic Reserve			
Bldg. 12-44 Cell 1	ENE	2,085	$2.1x10^{-7}$
HE Burning Ground	NNW	5,661	$6.4x10^{-8}$
Between Zone 11 and 12	NE	2,905	2.1x10-7
Strategic Reserve	NE	2,169	$3.3x10^{-7}$
Immobilization Facility	N	5,307	$1.7x10^{-7}$
LWR Site	NW	6,564	$5.2x10^{-8}$
Release Point: Immobilization Facility			
Bldg. 12-44 Cell 1	ESE	3,098	$8.7x10^{-8}$
HE Burning Ground	NNW	2,896	$1.7x10^{-7}$
Between Zone 11 and 12	E	2,733	1.6x10-7
Strategic Reserve	ESE	3,029	$9.0x10^{-8}$
Immobilization Facility	N	2,614	$4.8x10^{-7}$
LWR Site	NW	4,009	$1.0x10^{-7}$
Release Point: LWR Site			
Bldg. 12-44 Cell 1	ESE	6,344	$3.1x10^{-8}$
HE Burning Ground	NE	2,243	$3.1x10^{-7}$
Between Zone 11 and 12	ESE	5,935	3.4x10-8
Strategic Reserve	ESE	6,282	$3.1x10^{-8}$
Immobilization Facility	ENE	3,314	$1.0x10^{-7}$
LWR Site	N	1,380	$1.4x10^{-6}$

Source: HNUS 1996a.

Table M.2.7–3. Doses and Resulting Health Effects to the Maximally Exposed Individual at Pantex Plant From Atmospheric Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	4.3×10^{-6}	5.7×10^{-5}	4.0×10^{-15}	0.0	6.1×10^{-5}	1.8×10^{-5}	3.1×10^{-11}
Upgraded Storage Facility[b]	c	c	c	c	1.8×10^{-8}	5.4×10^{-9}	9.0×10^{-15}
Upgraded Consolidated Storage Facility	9.5×10^{-6}	1.7×10^{-8}	3.6×10^{-15}	7.6×10^{-12}	9.5×10^{-6}	2.8×10^{-6}	4.7×10^{-12}
Consolidated Storage Facility	9.5×10^{-6}	1.6×10^{-8}	3.6×10^{-15}	7.6×10^{-12}	9.5×10^{-6}	2.8×10^{-6}	4.7×10^{-12}
Collocated Storage Facility	9.6×10^{-6}	1.7×10^{-8}	3.8×10^{-15}	1.2×10^{-11}	9.6×10^{-6}	2.9×10^{-6}	4.8×10^{-12}
Pit Disassembly/Conversion Facility	1.1×10^{-3}	2.3×10^{-5}	6.3×10^{-12}	9.4×10^{-9}	1.1×10^{-3}	3.3×10^{-4}	5.5×10^{-10}
Pu Conversion Facility	6.9×10^{-4}	1.3×10^{-6}	2.9×10^{-13}	6.1×10^{-10}	6.9×10^{-4}	2.1×10^{-4}	3.5×10^{-10}
MOX Fuel Fabrication Facility	5.2×10^{-4}	8.9×10^{-7}	2.0×10^{-13}	9.4×10^{-10}	5.2×10^{-4}	1.6×10^{-4}	2.6×10^{-10}
Ceramic Immobilization Facility (Immobilization Disposition)	2.5×10^{-7}	4.3×10^{-10}	9.6×10^{-17}	2.0×10^{-13}	2.5×10^{-7}	7.5×10^{-8}	1.2×10^{-13}
Deep Borehole Complex (Direct Disposition)	4.1×10^{-8}	5.9×10^{-10}	1.5×10^{-16}	2.4×10^{-13}	4.1×10^{-8}	1.2×10^{-8}	2.1×10^{-14}
Deep Borehole Complex (Immobilized Disposition)	5.0×10^{-8}	8.8×10^{-10}	2.3×10^{-16}	3.4×10^{-13}	5.1×10^{-8}	1.5×10^{-8}	2.6×10^{-14}
Vitrification Facility	9.8×10^{-5}	6.7×10^{-6}	1.9×10^{-9}	1.1×10^{-6}	1.1×10^{-4}	3.3×10^{-5}	5.5×10^{-11}
Ceramic Immobilization Facility (Ceramic Immobilization)	2.8×10^{-7}	1.3×10^{-6}	4.0×10^{-10}	2.1×10^{-7}	1.8×10^{-6}	5.4×10^{-7}	9.0×10^{-13}
Advanced Boiling Water Reactor	1.7×10^{-2}	0.99	0.47	2.4×10^{-2}	1.5	0.45	7.5×10^{-7}
CE System 80+ Reactor	5.9×10^{-2}	1.1	2.7×10^{-2}	9.5×10^{-3}	1.2	0.36	6.0×10^{-7}
[Text deleted.]							
AP600 Reactor	3.2×10^{-2}	0.93	7.6×10^{-2}	1.4×10^{-2}	1.0	0.30	5.0×10^{-7}
RESAR-90 Reactor	5.0×10^{-2}	1.4	3.0×10^{-2}	1.2×10^{-2}	1.5	0.45	7.5×10^{-7}

[a] Individual annual natural background radiation dose is equal to 334 mrem.

[b] For the three upgrade subalternatives including the Preferred Alternative, the dose to the MEI and the population within 80 km would decrease slightly from the No Action Alternative, although the differences are expected to be below detection limits. Therefore, the total site dose would decrease slightly but the change would be undetectable. The quantity of Pu pits at Pantex to be stored in upgraded facilities in Zone 12 would be slightly increased by the addition of RFETS pits (the Preferred Alternative) or by the addition of RFETS Pu and LANL Pu. The difference between these three subalternatives would be below detection limits. The AT-400A has both an inner container and an outer container that provides additional shielding material. The overall effect of moving Pantex and RFETS pits from Zone 4 to upgraded Zone 12 storage facilities would be lower potential releases of radioactive materials to the public, because the radiological impacts at Zone 4 would be reduced.

[c] The committed effective dose equivalent for the storage facility is calculated to be 1.8×10^{-8} mrem based upon an analysis of measured dose. The dose shown here is for the Upgrade With RFETS Pu Pits Subalternative (Preferred Alternative). The dose for the Upgrade Without RFETS Pu or LANL Pu Subalternative would be slightly less and for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative would be slightly greater. The differences are not measurable above background.

Note: The dose shown here is for the Upgrade with RFETS Pu Pits Subalternative (Preferred Alternative). The dose for the Upgrade Without RFETS Pu or LANL Pu Subalternative would be slightly less and for the Upgrade With All or Some RGETS Pu and LANL Pu Subalternative would be slightly greater. The differences are not measurable above background.

Source: HNUS 1996a.

Table M.2.7–4. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Pantex Plant From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	6.1×10^{-6}	2.7×10^{-4}	5.7×10^{-15}	0.0	2.8×10^{-4}	2.4×10^{-7}	1.4×10^{-7}
Upgraded Storage Facility[b]	[c]	[c]	[c]	[c]	6.3×10^{-6}	5.4×10^{-9}	3.2×10^{-9}
Upgraded Consolidated Storage Facility	5.5×10^{-5}	5.4×10^{-7}	2.1×10^{-14}	4.3×10^{-11}	5.5×10^{-5}	4.7×10^{-8}	2.7×10^{-8}
Consolidated Storage Facility	5.2×10^{-5}	5.4×10^{-7}	2.0×10^{-14}	4.2×10^{-11}	5.2×10^{-5}	4.4×10^{-8}	2.6×10^{-8}
Collocated Storage Facilities	5.2×10^{-5}	5.4×10^{-7}	2.1×10^{-14}	6.3×10^{-11}	5.3×10^{-5}	4.5×10^{-8}	2.7×10^{-8}
Pit Disassembly/Conversion Facility	5.6×10^{-3}	7.5×10^{-4}	3.4×10^{-11}	5.1×10^{-8}	6.4×10^{-3}	5.5×10^{-6}	3.2×10^{-6}
Plutonium Conversion Facility	3.8×10^{-3}	4.1×10^{-5}	1.6×10^{-12}	3.4×10^{-9}	3.8×10^{-3}	3.3×10^{-6}	1.9×10^{-6}
MOX Fuel Fabrication Facility	2.8×10^{-3}	2.9×10^{-5}	1.1×10^{-12}	5.2×10^{-9}	2.8×10^{-3}	2.4×10^{-6}	1.4×10^{-6}
Ceramic Immobilization Facility (Immobilized Disposition)	6.3×10^{-7}	6.7×10^{-9}	2.4×10^{-16}	4.9×10^{-13}	6.3×10^{-7}	5.4×10^{-10}	3.1×10^{-10}
Deep Borehole Complex (Direct Disposition)	1.0×10^{-7}	9.3×10^{-9}	3.9×10^{-16}	6.0×10^{-13}	1.1×10^{-7}	9.4×10^{-11}	5.5×10^{-11}
Deep Borehole Complex (With Immobilization)	1.3×10^{-7}	1.4×10^{-8}	5.8×10^{-16}	8.6×10^{-13}	1.4×10^{-7}	1.2×10^{-10}	7.0×10^{-11}
Vitrification Facility	2.5×10^{-4}	8.7×10^{-5}	4.7×10^{-9}	2.7×10^{-6}	3.4×10^{-4}	2.9×10^{-7}	1.7×10^{-7}
Ceramic Immobilization Facility (Ceramic Immobilization)	7.0×10^{-7}	1.7×10^{-5}	9.8×10^{-10}	5.3×10^{-7}	1.9×10^{-5}	1.6×10^{-8}	9.5×10^{-9}
Advanced Boiling Water Reactor	1.5×10^{-2}	8.4	0.15	1.8×10^{-2}	8.5	7.3×10^{-3}	4.3×10^{-3}
CE System 80+ Reactor	5.1×10^{-2}	8.1	1.8×10^{-2}	8.4×10^{-3}	8.2	7.0×10^{-3}	4.1×10^{-3}
[Text deleted.]							
AP600 Reactor	2.8×10^{-2}	7.3	5.8×10^{-2}	1.3×10^{-2}	7.4	6.3×10^{-3}	3.7×10^{-3}
RESAR-90 Reactor	4.5×10^{-2}	8.8	2.4×10^{-2}	1.1×10^{-2}	8.9	7.6×10^{-3}	4.4×10^{-3}

[a] Dose to the population within 80 km from natural background radiation in 2030 is equal to 116,900 person-rem.

[b] For the three upgrade subalternatives including the Preferred Alternative, the dose to the MEI and the population within 80 km would decrease slightly from the No Action Alternative, although the differences are expected to be below detection limits. Therefore, the total site dose would decrease slightly but the change would be undetectable. The quantity of Pu pits at Pantex to be stored in upgraded facilities in Zone 12 would be slightly increased by the addition of RFETS pits (the Preferred Alternative) or by the addition of RFETS Pu and LANL Pu. The difference between these three subalternatives would be below detection limits. The AT-400A has both an inner container and an outer container that provides additional shielding material. The overall effect of moving Pantex and RFETS pits from Zone 4 to upgraded Zone 12 storage facilities would be lower potential releases of radioactive materials to the public, because the radiological impacts at Zone 4 would be reduced.

[c] The committed effective dose equivalent for the storage facility is calculated to be 1.8×10^{-8} mrem based upon an analysis of measured dose. The dose shown here is for the Upgrade With RFETS Pu Pits Subalternative (Preferred Alternative). The dose for the Upgrade Without RFETS Pu or LANL Pu Subalternative would be slightly less and for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative would be slightly greater. The differences are not measurable above background.

Note: The dose shown here is for the Upgrade with RFETS Pu Pits Subalternative (Preferred Alternative). The dose for the Upgrade Without RFETS Pu or LANL Pu Subalternative would be slightly less and for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative would be slightly greater. The differences are not measurable above background.

Source: HNUS 1996a.

M.2.7.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, two of the areas have radioactive releases into the atmosphere from normal operation. Table M.2.7.1–1 presents the estimated annual atmospheric radioactive releases for No Action.

Table M.2.7.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Pantex Plant (curies)

	Weapons Assembly/ Disassembly High Explosive	
Isotope	Bldg. 12-44 Cell 1	Burning Ground
Tritium (H-3)	0.16	0.14

Source: PX 1995a:1; PX DOE 1994a; PX DOE 1995d.

Tables M.2.7–3 and M.2.7–4 include the radiological impacts to the MEI and the offsite population within 80 km (50 mi), respectively. The MEI would receive an annual dose of 6.1×10^{-5} mrem. An estimated fatal cancer risk of 1.5×10^{-9} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 2.8×10^{-4} person-rem in 2030 (mid-life of operation). An estimated 7.0×10^{-6} fatal cancers could result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. There are no radioactive liquid releases into the offsite environment associated with No Action. Therefore, there are no resulting impacts.

Worker Doses and Health Effects. Based on measured values during the time period from 1989 to 1992 (*Twenty-Second Annual Report Radiation Exposure for DOE and DOE Contractor Employees–1989*, DOE/EH-0286P) and subsequent yearly dose reports), the annual average dose to a badged worker at Pantex was calculated to be 15 mrem. It is projected that in 2005 and beyond, there would be 1,400 badged workers involved in No Action activities at Pantex (PX 1995a:1). The annual average dose to these workers was assumed to be 10 mrem; the annual total dose among all these workers would then equal 14 person-rem. From 50 years of operation, an estimated fatal cancer risk of 2.0×10^{-4} would result to the average worker and 0.28 fatal cancers could result among all workers.

M.2.7.2 Storage and Disposition

Radioactive Releases and Resulting Impacts to the Public. Total site radiological impacts during operation of storage or disposition facilities can be found by adding the impacts resulting from No Action facilities to the changes in impacts resulting from the storage or disposition facilities. For example, to determine the radiological impact for the addition of the AP600 reactor at Pantex, the No Action facilities doses have to be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases for the different facilities are given in Section M.2.3. Tables M.2.7–3 and M.2.7–4 include the radiological impacts by alternative. There are no radioactive liquid releases into the offsite environment associated with any alternative action.

No change was reported in radioactive releases due to the upgrade of existing storage facilities for continued Pu storage at Pantex above those radioactive releases already included in No Action. Therefore, there are no changes in dose to the public from the upgrade of existing storage facilities at Pantex.

The annual doses associated with the different alternatives range from 0 to 1.5 mrem to the MEI and from 0 to 8.9 person-rem to the 80-km (50-mi) population in 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the changes in impacts from the storage or disposition facilities to determine the impacts from total site operations (refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.8 RADIOLOGICAL IMPACTS AT OAK RIDGE RESERVATION

This section presents the radiological impacts of the various storage and disposition alternatives at ORR. Section M.2.8.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.8.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modeling, ORR was divided into seven separate areas which would release radioactivity in 2005. All potential release points in each area were aggregated into a single release point. Tables M.2.8–1 and M.2.8–2 present the characteristics of each of the release points including location, release height, minimum distance, and annual average dispersion to the site boundary in each of 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For further clarification on the definition of the "maximum receptor," refer to Section M.2.2.2. For example, the dose resulting from releases from the Oak Ridge National Laboratory (ORNL), Y–12 Plant (Y–12), High Flux Isotope Reactor Areas, and the other storage and disposition alternatives, has been determined for the maximum receptor from the K–25 Site (K–25) incinerator. Figure M.2.8–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred to the site MEI) is then determined by the maximum dose to one of those maximum receptors. Tables M.2.8–3 and M.2.8–4 present the distance, direction, and atmospheric dispersion from each release point to each of the maximum receptors. Annual radiological releases were assumed to remain constant during the full operational period.

Descriptions of population, foodstuffs distributions, and aquatic foods for each release area are provided in a Health Risk Data report, October 1996. The joint frequency distributions used for the dose assessment were based on 1990 meteorological measurements from five meteorological towers (Tower 1 for K–25, Tower 2 for ORNL, Tower 4 for the High Flux Isotope Reactor and Radiochemical Engineering Development Center, Tower 5 for Y–12, and Tower 6 for the proposed Tritium Supply Site location) at the 10-m (33-ft) height and are contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables and for the projected operational period in the text. Tables M.2.8–5 through M.2.8–8 include the radiological impacts to the public from both atmospheric release and from using the surface water for No Action and the storage and disposition alternatives.

Table M.2.8–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Oak Ridge Reservation Boundary (Without Presence of the Clinch River Breeder Reactor Site)

Release Point[a]	Immobilization Facility		K-25		X-10	
Latitude	35°55'59.139"		35°56'15.444"		35°55'39.169"	
Longitude	-84°20'55.855"		-84°22'54.796"		-84°18'55.580"	
Release Height	Ground Level		Ground Level		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary					
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	3,200	2.2×10^{-7}	3,037	1.7×10^{-7}	4,218	2.1×10^{-7}
NNE	2,996	5.8×10^{-7}	3,919	3.2×10^{-7}	5,872	2.3×10^{-7}
NE	4,624	6.2×10^{7}	4,360	5.0×10^{-7}	8,512	2.0×10^{-7}
ENE	9,494	2.9×10^{-7}	4,633	4.8×10^{-7}	3,935	4.4×10^{-7}
E	6,806	1.5×10^{-7}	9,767	1.1×10^{-7}	4,337	2.3×10^{-7}
ESE	6,782	1.2×10^{-7}	9,643	6.1×10^{-8}	4,390	1.9×10^{-7}
SE	5,900	6.9×10^{-8}	4,931	1.1×10^{-7}	4,029	2.5×10^{-7}
SSE	3,558	6.1×10^{-8}	2,313	4.0×10^{-7}	4,367	2.0×10^{-7}
S	3,417	8.7×10^{-8}	2,414	6.1×10^{-7}	4,296	1.7×10^{-7}
SSW	3,851	3.2×10^{-7}	3,303	4.8×10^{-7}	3,752	2.4×10^{-7}
SW	2,903	1.1×10^{-6}	3,897	2.6×10^{-7}	3,750	4.5×10^{-7}
WSW	4,897	2.1×10^{-7}	2,892	5.9×10^{-7}	5,340	2.6×10^{-7}
W	5,700	5.6×10^{-8}	3,600	2.1×10^{-7}	8,677	4.5×10^{-8}
WNW	4,299	4.7×10^{-8}	2,775	1.2×10^{-7}	7,267	3.8×10^{-8}
NW	4,788	3.9×10^{-8}	2,374	1.3×10^{-7}	4,474	8.1×10^{-8}
NNW	4,767	4.7×10^{-8}	1,856	2.6×10^{-7}	3,900	9.4×10^{-8}

Table M.2.8–1. Release Point Characteristics, Direction, Distance, and Chi/Q at the Oak Ridge Reservation Boundary (Without Presence of the Clinch River Breeder Reactor Site)—Continued

Release Point[a]	Y–12		MOX Fuel Fabrication		Pit Disassembly/Conversion	
Latitude	35°59'8.409"		35°59'.676"		35°58'50.204"	
Longitude	-84°15'38.488"		-84°15'43.725"		-84°16'13.244"	
Release Height	20.0 m		Ground Level		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary					
Direction	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**
N	675	$7.7x10^{-7}$	824	$1.9x10^{-6}$	839	$2.1x10^{-6}$
NNE	879	$1.0x10^{-6}$	1,070	$3.2x10^{-6}$	1,082	$3.1x10^{-6}$
NE	1,618	$9.8x10^{-7}$	1,982	$1.6x10^{-6}$	1,683	$3.0x10^{-6}$
ENE	2,360	$6.6x10^{-7}$	2,671	$8.3x10^{-7}$	3,396	$1.3x10^{-6}$
E	2,963	$3.4x10^{-7}$	2,765	$8.4x10^{-7}$	2,970	$5.2x10^{-7}$
ESE	2,283	$2.8x10^{-7}$	2,268	$2.0x10^{-7}$	2,837	$4.4x10^{-7}$
SE	2,329	$2.1x10^{-7}$	3,663	$5.3x10^{-8}$	3,719	$1.4x10^{-7}$
SSE	3,726	$1.3x10^{-7}$	3,570	$1.2x10^{-7}$	4,276	$4.6x10^{-8}$
S	4,682	$1.5x10^{-7}$	4,432	$8.9x10^{-8}$	4,100	$6.6x10^{-8}$
SSW	9,589	$7.2x10^{-8}$	9,563	$5.7x10^{-8}$	10,586	$7.5x10^{-8}$
SW	11,872	$3.8x10^{-8}$	11,602	$1.6x10^{-7}$	10,901	$1.7x10^{-7}$
WSW	3,454	$2.4x10^{-7}$	3,733	$7.3x10^{-7}$	3,306	$3.8x10^{-7}$
W	1,082	$5.3x10^{-7}$	1,370	$1.2x10^{-6}$	1,349	$5.7x10^{-7}$
WNW	810	$4.8x10^{-7}$	974	$6.4x10^{-7}$	921	$6.4x10^{-7}$
NW	688	$5.2x10^{-7}$	862	$6.6x10^{-7}$	801	$7.8x10^{-7}$
NNW	619	$7.1x10^{-7}$	798	$9.1x10^{-7}$	772	$1.1x10^{-6}$

[a] See Figure M.2.8–1 for location of release points.

Source: HNUS 1996a

Table M.2.8–2. Release Point Characteristics, Direction, Distance, and Chi/Q at the Oak Ridge Reservation Boundary (With Presence of the Clinch River Breeder Reactor Site)

Release Point[a]	LWR Site		Immobilization Facility		K-25		X-10	
Latitude	35°54'9.137"		35°55'59.139"		35°56'15.444"		35°55'39.169"	
Longitude	-84°22'45.671"		-84°20'55.855"		-84°22'54.796"		-84°18'55.580"	
Release Height	Ground Level		Ground Level		Ground Level		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary							
Direction	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**
N	930	2.5×10^{-6}	3,199	2.2×10^{-7}	3,041	1.7×10^{-7}	4,206	2.1×10^{-7}
NNE	1,209	2.7×10^{-6}	2,995	5.8×10^{-7}	3,936	3.2×10^{-7}	5,852	2.3×10^{-7}
NE	8,444	2.0×10^{-7}	4,646	6.2×10^{7}	4,362	5.0×10^{-7}	8,512	2.0×10^{-7}
ENE	11,141	9.5×10^{-8}	9,893	2.7×10^{-7}	4,634	4.8×10^{-7}	5,162	2.9×10^{-7}
E	2,171	6.8×10^{-7}	7,827	1.2×10^{-7}	10,817	9.6×10^{-8}	4,863	2.0×10^{-7}
ESE	898	2.5×10^{-6}	7,133	1.1×10^{-7}	9,987	5.8×10^{-8}	4,707	1.7×10^{-7}
SE	830	3.4×10^{-6}	6,077	6.7×10^{-8}	5,089	1.0×10^{-7}	4,385	2.2×10^{-7}
SSE	979	2.3×10^{-6}	4,081	4.9×10^{-8}	2,306	4.0×10^{-7}	4,586	1.9×10^{-7}
S	2,154	5.0×10^{-7}	3,788	7.5×10^{-8}	2,418	6.1×10^{-7}	4,483	1.6×10^{-7}
SSW	1,863	7.2×10^{-7}	4,000	3.0×10^{-7}	3,436	4.5×10^{-7}	3,956	2.2×10^{-7}
SW	998	3.9×10^{-6}	2,903	1.1×10^{-6}	3,897	2.6×10^{-7}	4,134	3.9×10^{-7}
WSW	897	4.5×10^{-6}	5,279	1.9×10^{-7}	2,892	5.9×10^{-7}	5,340	2.6×10^{-7}
W	939	1.6×10^{-6}	5,700	5.6×10^{-8}	3,618	2.1×10^{-7}	8,677	4.5×10^{-8}
WNW	854	1.2×10^{-6}	4,294	4.7×10^{-8}	2,782	1.2×10^{-7}	7,259	3.8×10^{-8}
NW	755	1.5×10^{-6}	4,787	3.9×10^{-8}	2,355	1.3×10^{-7}	4,460	8.1×10^{-8}
NNW	764	1.4×10^{-6}	4,769	4.7×10^{-8}	1,855	2.6×10^{-7}	3,900	9.4×10^{-8}

Table M.2.8–2. Release Point Characteristics, Direction, Distance, and Chi/Q at the Oak Ridge Reservation Boundary (With Presence of the Clinch River Breeder Reactor Site)—Continued

Release Point[a]	Y–12		MOX Fuel Fabrication		Pit Disassembly/Conversion	
Latitude	35°59'8.409"		35°59'.676"		35°58'50.204"	
Longitude	-84°15'38.488"		-84°15'43.725"		-84°16'13.244"	
Release Height	20 m		Ground Level		Ground Level	
	Distance and Atmospheric Dispersion at Site Boundary					
Direction	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**	**Distance (m)**	**Chi/Q (s/m^3)**
N	657	7.9×10^{-7}	821	1.9×10^{-6}	826	2.1×10^{-6}
NNE	897	1.0×10^{-6}	1,087	3.1×10^{-6}	1,067	3.1×10^{-6}
NE	1,639	9.7×10^{-7}	2,000	1.5×10^{-6}	1,658	3.0×10^{-6}
ENE	2,344	6.6×10^{-7}	2,658	8.3×10^{-7}	3,380	1.3×10^{-6}
E	2,936	3.5×10^{-7}	2,772	8.4×10^{-7}	2,978	5.2×10^{-7}
ESE	2,286	2.8×10^{-7}	2,273	2.0×10^{-7}	2,844	4.4×10^{-7}
SE	2,320	2.1×10^{-7}	4,125	4.4×10^{-8}	4,241	1.1×10^{-7}
SSE	4,229	1.1×10^{-7}	4,085	9.5×10^{-8}	5,014	3.6×10^{-8}
S	5,423	1.3×10^{-7}	5,197	7.0×10^{-8}	5,193	4.6×10^{-8}
SSW	11,713	5.5×10^{-8}	11,444	4.4×10^{-8}	10,902	7.2×10^{-8}
SW	12,181	3.7×10^{-8}	11,898	1.5×10^{-7}	11,310	1.6×10^{-7}
WSW	3,433	2.4×10^{-7}	3,712	7.4×10^{-7}	3,330	3.8×10^{-7}
W	1,067	5.3×10^{-7}	1,353	1.2×10^{-6}	1,327	5.9×10^{-7}
WNW	803	4.9×10^{-7}	963	6.6×10^{-7}	911	6.5×10^{-7}
NW	687	5.2×10^{-7}	868	6.5×10^{-7}	795	8.0×10^{-7}
NNW	621	7.1×10^{-7}	805	9.0×10^{-7}	773	1.1×10^{-6}

[a] See Figure M.2.8–1 for location of release points.

Source: HNUS 1996a.

Table M.2.8–3. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Oak Ridge Reservation Site Boundary (Without Presence of the Clinch River Breeder Reactor Site)

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: Immobilization			
Immobilization Facility	SW	2,903	1.1×10^{-6}
K–25	SW	3,189	9.7×10^{-7}
X–10	SSE	3,582	6.0×10^{-8}
Y–12	NE	10,548	1.9×10^{-7}
MOX Fuel Fabrication	NE	10,449	1.9×10^{-7}
Pit Disassembly/Conversion	NE	9,699	2.1×10^{-7}
Release Point: K–25			
Immobilization Facility	SSE	2,315	4.0×10^{-7}
K–25	S	2,415	6.1×10^{-7}
X–10	SE	5,421	9.3×10^{-8}
Y–12	ENE	12,739	1.1×10^{-7}
MOX Fuel Fabrication	ENE	12,639	1.1×10^{-7}
Pit Disassembly/Conversion	ENE	11,863	1.2×10^{-7}
Release Point: X–10			
Immobilization Facility	WSW	5,468	2.5×10^{-7}
K–25	WSW	5,735	2.3×10^{-7}
X–10	SW	3,750	4.5×10^{-7}
Y–12	NNE	8,933	1.2×10^{-7}
MOX Fuel Fabrication	NNE	8,842	1.3×10^{-7}
Pit Disassembly/Conversion	NNE	8,184	1.4×10^{-7}
Release Point: Y–12			
Immobilization Facility	SW	12,769	3.4×10^{-8}
K–25	SW	13,055	3.3×10^{-8}
X–10	SW	11,875	3.8×10^{-8}
Y–12	NNE	879	1.0×10^{-6}
MOX Fuel Fabrication	N	812	6.4×10^{-7}
Pit Disassembly/Conversion	NW	772	4.5×10^{-7}

Table M.2.8–3. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Oak Ridge Reservation Site Boundary (Without Presence of the Clinch River Breeder Reactor Site)—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: MOX Fuel Fabrication Facility			
Immobilization Facility	SW	12,523	$1.4x10^{-7}$
K–25	SW	12,809	$1.4x10^{-7}$
X–10	SW	11,606	$1.6x10^{-7}$
Y–12	NN	1,143	$2.8x10^{-6}$
MOX Fuel Fabrication	NNE	1,071	$3.1x10^{-6}$
Pit Disassembly/Conversion	NW	863	$6.6x10^{-7}$
Release Point: Pit Disassembly/ Conversion			
Immobilization Facility	SW	11,735	$1.5x10^{-7}$
K–25	SW	12,021	$1.5x10^{-7}$
X–10	SW	10,902	$1.7x10^{-7}$
Y–12	NE	1,776	$2.7x10^{-6}$
MOX Fuel Fabrication	NE	1,683	$3.0x10^{-6}$
Pit Disassembly/Conversion	NNE	1,083	$3.1x10^{-6}$

Source: HNUS 1996a.

Table M.2.8–4. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Oak Ridge Reservation Site Boundary (With Presence of the Clinch River Breeder Reactor Site)

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: LWR Site			
LWR Site	WSW	897	4.5×10^{-6}
Immobilization Facility	NNE	1,728	1.5×10^{-6}
K–25	N	1,518	1.1×10^{-6}
X–10	E	3,420	3.4×10^{-7}
Y–12	NE	14,878	9.2×10^{-8}
MOX Fuel Fabrication	NE	14,780	9.2×10^{-8}
Pit Disassembly/Conversion	NE	13,996	1.0×10^{-7}
Release Point: Immobilization			
LWR Site	SSW	4,244	2.8×10^{-7}
Immobilization Facility	SW	2,903	1.1×10^{-6}
K–25	SW	3,198	9.7×10^{-7}
X–10	S	4,027	6.8×10^{-8}
Y–12	NE	10,571	1.9×10^{-7}
MOX Fuel Fabrication	NE	10,472	1.9×10^{-7}
Pit Disassembly/Conversion	NE	9,674	2.2×10^{-7}
Release Point: K–25 TSCA Incinerator			
LWR Site	S	4,244	2.6×10^{-7}
Immobilization Facility	SSE	2,306	4.0×10^{-7}
K–25	S	2,419	6.1×10^{-7}
X–10	SE	5,747	8.5×10^{-8}
Y–12	ENE	12,761	1.1×10^{-7}
MOX Fuel Fabrication	ENE	12,663	1.1×10^{-7}
Pit Disassembly/Conversion	ENE	11,836	1.3×10^{-7}
Release Point: X–10 (ORNL)			
LWR Site	WSW	7,297	1.6×10^{-7}
Immobilization Facility	WSW	5,471	2.5×10^{-7}
K–25	WSW	5,743	2.3×10^{-7}
X–10	SW	4,135	3.9×10^{-7}
Y–12	NNE	8,956	1.2×10^{-7}
MOX Fuel Fabrication	NNE	8,863	1.3×10^{-7}
Pit Disassembly/Conversion	NNE	8,163	1.4×10^{-7}

Table M.2.8–4. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Oak Ridge Reservation Site Boundary (With Presence of the Clinch River Breeder Reactor Site)—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: Y–12			
LWR Site	SW	14,978	$2.8x10^{-8}$
Immobilization Facility	SW	12,769	$3.4x10^{-8}$
K–25	SW	13,064	$3.3x10^{-8}$
X–10	SW	12,259	$3.6x10^{-8}$
Y–12	NNE	898	$1.0x10^{-6}$
MOX Fuel Fabrication	N	827	$6.2x10^{-7}$
Pit Disassembly/Conversion	NW	785	$4.4x10^{-7}$
Release Point: MOX Fuel Fabrication Facility			
LWR Site	SW	14,726	$1.1x10^{-7}$
Immobilization Facility	SW	12,523	$1.4x10^{-7}$
K–25	SW	12,818	$1.4x10^{-7}$
X–10	SW	11,989	$1.5x10^{-7}$
Y–12	NNE	1,163	$2.7x10^{-6}$
MOX Fuel Fabrication	NNE	1,087	$3.1x10^{-6}$
Pit Disassembly/Conversion	NW	868	$6.5x10^{-7}$
Release Point: Pit Disassembly/ Conversion			
LWR Site	SW	13,950	$1.2x10^{-7}$
Immobilization Facility	SW	11,735	$1.5x10^{-7}$
K–25	SW	12,030	$1.5x10^{-7}$
X–10	SSW	11,293	$6.9x10^{-7}$
Y–12	NE	1,798	$2.7x10^{-6}$
MOX Fuel Fabrication	NE	1,705	$2.9x10^{-6}$
Pit Disassembly/Conversion	NNE	1,067	$3.1x10^{-6}$

Source: HNUS 1996a.

Table M.2.8–5. Doses and Resulting Health Effects to the Maximally Exposed Individual at Oak Ridge Reservation From Atmospheric Releases Associated With Annual Normal Operation

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	1.4	1.7×10^{-2}	3.2×10^{-2}	5.3×10^{-4}	1.5	5.0×10^{-1}	7.4×10^{-7}
Upgrade HEU Storage	2.2×10^{-7}	5.3×10^{-10}	8.8×10^{-16}	1.7×10^{-11}	2.2×10^{-7}	7.5×10^{-8}	1.1×10^{-13}
[Text deleted.]							
Collocated Storage Facility	4.4×10^{-5}	8.0×10^{-8}	1.8×10^{-14}	5.5×10^{-11}	4.5×10^{-5}	1.5×10^{-5}	2.3×10^{-11}
Pit Disassembly/Conversion Facility	1.3×10^{-2}	3.0×10^{-4}	7.9×10^{-11}	1.2×10^{-7}	1.4×10^{-2}	4.7×10^{-3}	7.0×10^{-9}
Pu Conversion Facility	9.1×10^{-3}	1.7×10^{-5}	3.9×10^{-12}	8.2×10^{-8}	9.2×10^{-3}	3.1×10^{-3}	4.6×10^{-9}
MOX Fuel Fabrication Facility	6.8×10^{-3}	1.2×10^{-5}	2.6×10^{-12}	1.2×10^{-8}	6.8×10^{-3}	2.3×10^{-3}	3.4×10^{-9}
Ceramic Immobilization Facility (Immobilized Disposition)	5.9×10^{-7}	1.0×10^{-9}	2.2×10^{-16}	4.6×10^{-13}	5.9×10^{-7}	2.0×10^{-7}	3.0×10^{-13}
Deep Borehole Complex (Direct Disposition)	9.3×10^{-8}	1.4×10^{-9}	3.7×10^{-16}	5.6×10^{-13}	9.4×10^{-8}	3.2×10^{-8}	4.7×10^{-14}
Deep Borehole Complex (Immobilized Disposition)	1.2×10^{-7}	2.0×10^{-9}	5.4×10^{-16}	7.9×10^{-13}	1.2×10^{-7}	4.1×10^{-8}	6.0×10^{-14}
Vitrification Facility	2.3×10^{-4}	1.5×10^{-5}	4.4×10^{-9}	2.5×10^{-6}	2.5×10^{-4}	8.5×10^{-5}	1.3×10^{-10}
Ceramic Immobilization Facility (Ceramic Immobilization)	6.5×10^{-7}	3.0×10^{-6}	9.1×10^{-10}	4.9×10^{-7}	4.2×10^{-6}	1.4×10^{-6}	2.1×10^{-12}
Advanced Boiling Water Reactor	4.9×10^{-2}	3.2	1.5	6.7×10^{-2}	4.8	1.6	2.4×10^{-6}
CE System 80+ Reactor	1.1×10^{-1}	3.1	8.9×10^{-2}	1.4×10^{-3}	3.3	1.1	1.7×10^{-6}
[Text deleted.]							
AP600 Reactor	2.5×10^{-2}	2.1	2.5×10^{-1}	1.5×10^{-2}	2.3	7.8×10^{-1}	1.2×10^{-6}
RESAR-90 Reactor	9.0×10^{-2}	3.2	1.0×10^{-1}	1.7×10^{-2}	3.5	1.2	1.8×10^{-6}

[a] Individual annual natural background radiation dose is equal to 295 mrem.

[Text deleted.]

Source: HNUS 1996a.

Table M.2.8–6. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Oak Ridge Reservation From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent in 2030 (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	26	0.41	2.3	5.7×10^{-2}	29	7.7×10^{-3}	1.5×10^{-2}
Upgrade HEU Storage	3.4×10^{-6}	8.0×10^{-10}	1.4×10^{-14}	2.7×10^{-10}	3.4×10^{-6}	9.0×10^{-10}	1.7×10^{-9}
[Text deleted.]							
Collocated Storage Facilities	8.7×10^{-4}	1.4×10^{-7}	3.5×10^{-13}	1.0×10^{-9}	8.7×10^{-4}	2.3×10^{-7}	4.4×10^{-7}
Pit Disassembly/Conversion Facility	0.12	1.7×10^{-4}	6.9×10^{-10}	1.0×10^{-6}	0.12	3.2×10^{-5}	6.0×10^{-5}
Pu Conversion Facility	7.4×10^{-2}	9.3×10^{-6}	3.2×10^{-11}	6.6×10^{-8}	7.4×10^{-2}	2.0×10^{-5}	3.7×10^{-5}
MOX Fuel Fabrication Facility	4.8×10^{-2}	6.3×10^{-6}	1.9×10^{-11}	9.1×10^{-8}	4.8×10^{-2}	1.3×10^{-5}	2.4×10^{-5}
Ceramic Immobilization Facility (Immobilized Disposition)	1.1×10^{-5}	1.7×10^{-9}	4.2×10^{-15}	8.5×10^{-12}	1.1×10^{-5}	2.9×10^{-9}	5.5×10^{-9}
Deep Borehole Complex (Direct Disposition)	1.8×10^{-6}	2.3×10^{-9}	6.9×10^{-15}	1.1×10^{-11}	1.8×10^{-6}	4.7×10^{-10}	9.0×10^{-10}
Deep Borehole Complex (Immobilized Disposition)	2.2×10^{-6}	3.4×10^{-9}	1.0×10^{-14}	1.5×10^{-11}	2.2×10^{-6}	5.8×10^{-10}	1.1×10^{-9}
Vitrification Facility	4.3×10^{-3}	5.0×10^{-5}	8.7×10^{-8}	4.7×10^{-5}	4.4×10^{-3}	1.2×10^{-6}	2.2×10^{-6}
Ceramic Immobilization Facility (Ceramic Immobilization)	1.2×10^{-5}	9.8×10^{-6}	1.7×10^{-8}	9.6×10^{-6}	3.2×10^{-5}	8.4×10^{-9}	1.6×10^{-8}
Advanced Boiling Water Reactor	0.16	3.1	1.7	0.19	5.1	1.3×10^{-3}	2.6×10^{-3}
CE System 80+ Reactor	0.39	2.8	0.21	4.9×10^{-3}	3.4	9.0×10^{-4}	1.7×10^{-3}
[Text deleted.]							
AP600 Reactor	8.7×10^{-2}	1.9	0.69	5.2×10^{-2}	2.8	7.4×10^{-4}	1.4×10^{-3}
RESAR-90 Reactor	0.31	3.0	0.29	5.8×10^{-2}	3.6	9.5×10^{-4}	1.8×10^{-3}

[a] Dose to the population within 80 km from natural background radiation in year 2030 is equal to 379,000 person-rem.

[Text deleted.]

Source: HNUS 1996a.

Table M.2.8–7. Doses and Resulting Health Effects to the Maximally Exposed Individual at Oak Ridge Reservation From Liquid Releases Associated With Annual Normal Operation

Alternative/ Facility	Dose by Pathway (mrem)						Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated Risk of 1-Year Fatal Cancers
	Fish Ingestion	Other Food Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	1.6	1.0×10^{-1}	1.2×10^{-2}	1.5×10^{-5}	3.0×10^{-5}	6.1×10^{-3}	1.7	5.8×10^{-1}	8.6×10^{-7}
Advanced Boiling Water Reactor	2.7×10^{-2}	1.0×10^{-3}	3.2×10^{-2}	2.6×10^{-6}	5.3×10^{-6}	2.9×10^{-4}	6.0×10^{-2}	2.0×10^{-2}	3.0×10^{-8}
CE System 80+ Reactor	9.0×10^{-2}	6.7×10^{-3}	2.0×10^{-1}	5.1×10^{-6}	1.0×10^{-5}	8.0×10^{-4}	3.0×10^{-1}	1.0×10^{-1}	1.5×10^{-7}
[Text deleted.]									
AP600 Reactor	1.0×10^{-1}	1.1×10^{-2}	3.6×10^{-1}	5.7×10^{-6}	1.1×10^{-5}	8.5×10^{-4}	4.7×10^{-1}	1.6×10^{-1}	2.4×10^{-7}
RESAR-90 Reactor	8.0×10^{-2}	1.4×10^{-2}	4.5×10^{-1}	5.7×10^{-6}	1.1×10^{-5}	4.9×10^{-4}	5.4×10^{-1}	1.8×10^{-1}	2.7×10^{-7}

[a] Individual annual natural background radiation dose is equal to 295 mrem.

Source: HNUS 1996a.

Table M.2.8–8. Doses and Resulting Health Effects to the Population Downstream of Oak Ridge Reservation From Liquid Releases Associated With Normal Operation in 2030

Alternative/ Facility	Dose by Pathway (person-rem)						Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Fish Ingestion	Other Food Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	2.3	2.3	0	6.8×10^{-4}	5.8×10^{-4}	4.8×10^{-2}	4.7	1.2×10^{-3}	2.3×10^{-3}
Advanced Boiling Water Reactor	5.2×10^{-2}	2.3×10^{-2}	0	1.2×10^{-4}	1.1×10^{-4}	2.3×10^{-3}	7.8×10^{-2}	2.1×10^{-5}	3.9×10^{-5}
CE System 80+ Reactor	1.4×10^{-1}	1.5×10^{-1}	0	2.4×10^{-4}	2.1×10^{-4}	6.4×10^{-3}	3.0×10^{-1}	7.9×10^{-5}	1.5×10^{-4}
[Text deleted.]			0						
AP600 Reactor	2.3×10^{-1}	2.6×10^{-1}	0	2.7×10^{-4}	2.3×10^{-4}	6.8×10^{-3}	5.0×10^{-1}	1.3×10^{-4}	2.5×10^{-4}
RESAR-90 Reactor	1.5×10^{-1}	3.2×10^{-1}	0	2.6×10^{-4}	2.3×10^{-4}	3.9×10^{-3}	4.8×10^{-1}	1.3×10^{-4}	2.4×10^{-4}

[a] Total dose to the population within 80 km from natural background radiation in year 2030 is equal to 379,000 person-rem.

Source: HNUS 1996a.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables and for the projected operational period in the test.

M.2.8.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, three of the five areas have radioactive releases into the atmosphere from normal operation. Table M.2.8.1–1 presents the estimated annual atmospheric radioactive releases.

Tables M.2.8–5 and M.2.8–6 include the atmospheric radiological impacts to the maximally exposed member of the public and the offsite population within 80 km (50 mi), respectively. The maximally exposed individual would receive an annual dose of 1.5 mrem. An estimated fatal cancer risk of 3.7×10^{-5} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 29 person-rem in 2030 (midlife of operation). An estimated 0.73 fatal cancers could result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. For No Action, two of the five areas have radioactive releases to the offsite surface water from normal operation. Table M.2.8.1–2 presents the estimated annual liquid radioactive releases.

Tables M.2.8–7 and M.2.8–8 include the radiological impacts to the maximally exposed individual and the offsite populations using surface water within 80 km (50 mi) downstream of ORR, respectively. The maximally exposed member of the public would receive an annual dose of 1.7 mrem. An estimated fatal cancer risk of 4.3×10^{-5} would result from 50 years of operation. The population would receive a dose of 4.7 person-rem in 2030. An estimated 0.12 fatal cancers could result from 50 years of operation.

Worker Doses and Health Effects. Based on measured values during 1991 and 1992 (Dose Reports for 1991 and 1992), it is estimated that the average dose to a badged worker involved in No Action activities at ORR in 2005 and beyond would equal 2.6 mrem. It is projected that in 2005 and beyond, there would be 17,215 badged workers involved in No Action activities. The annual dose among all these workers would equal 44 person-rem. From 50 years of operation, an estimated fatal cancer risk of 5.2×10^{-5} would result to the average worker and 0.88 fatal cancers could result among all workers.

Table M.2.8.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Oak Ridge Reservation (curies)

Isotope	K–25	X-10	Y–12	No Action HEU Storage[a]
H-3	0	$2.4x10^{2}$	0	0
Be-7	0	$3.8x10^{-4}$	0	0
K-40	$4.0x10^{-2}$	0	0	0
Ar-41	0	$1.8x10^{3}$	0	0
Co-57	$1.2x10^{-4}$	0	0	0
Co-60	$4.4x10^{-3}$	$2.6x10^{-6}$	0	0
Sr-90	0	$3.8x10^{-4}$	0	0
Tc-99	0.12	0	0	0
Ru-106	$4.5x10^{-3}$	0	0	0
Cd-109	$7.6x10^{-3}$	0	0	0
I-129	0	$2.5x10^{-4}$	0	0
I-130	0	$5.5x10^{-5}$	0	0
I-131	0	$5.3x10^{-2}$	0	0
I-132	0	0.93	0	0
I-133	0	0.20	0	0
I-135	0	0.47	0	0
Xe-135	0	$5.0x10^{1}$	0	0
Xe-138	0	$7.1x10^{1}$	0	0
Cs-134	0	$5.2x10^{-7}$	0	0
Cs-137	$5.0x10^{-3}$	$5.1x10^{-4}$	0	0
Cs-138	0	$7.1x10^{1}$	0	0
Ba-140	0	$4.9x10^{-4}$	0	0
Ce-141	$2.0x10^{-4}$	0	0	0
Eu-152	0	$1.7x10^{-6}$	0	0
Eu-154	0	$2.5x10^{-6}$	0	0
Eu-155	0	$5.2x10^{-6}$	0	0
Os-191	0	0.17	0	0
Pb-212	0	0.37	0	0
Th-228	$3.8x10^{-4}$	$1.5x10^{-6}$	0	0
Th-230	$5.9x10^{-5}$	$5.7x10^{-8}$	0	0
Th-232	$1.1x10^{-4}$	$3.3x10^{-8}$	0	0
Th-234	$1.8x10^{-2}$	0	0	0
U-234	$4.0x10^{-3}$	$8.7x10^{-6}$	$4.7x10^{-2}$	$4.7x10^{-5}$
U-235	$1.8x10^{-4}$	$4.7x10^{-7}$	$1.5x10^{-3}$	$1.5x10^{-6}$
U-236	0	0	$1.9x10^{-4}$	$1.9x10^{-7}$
U-238	$4.2x10^{-3}$	$2.8x10^{-5}$	$6.5x10^{-3}$	$6.5x10^{-6}$
Np-237	$5.7x10^{-4}$	0	0	0
Pu-238	$2.5x10^{-4}$	$2.8x10^{-6}$	0	0
Pu-239	$5.7x10^{-5}$	$8.0x10^{-6}$	0	0
Am-241	0	$4.6x10^{-6}$	0	0
Cm-244	0	$7.3x10^{-5}$	0	0

[a] No Action HEU storage release is assumed equal to 0.001 of Y–12 releases.
Source: OR DOE 1994c.

Table M.2.8.1–2. Annual Liquid Releases From Normal Operation of No Action at Oak Ridge Reservation (curies)

Isotope	K-25	X-10
H-3	0	$1.8x10^{-3}$
K-40	0.019	0
Co-60	0	0.55
Sr-90	0	6.7
Tc-99	0.030	0
Ru-106	0.038	0
Cs-137	$1.2x10^{-3}$	0.018
Ce-143	0.20	0.040
Th-228	0.20	0
Th-230	$2.4x10^{-5}$	0
Th-234	0.036	0
U-234	$7.7x10^{-3}$	$9.5x10^{-4}$
U-235	0.014	0.056
U-236	$5.8x10^{-4}$	0
U-238	$6.0x10^{-3}$	4.5
Np-237	$1.2x10^{-3}$	0
Pu-238	$1.6x10^{-4}$	0

Source: OR DOE 1994c.

M.2.8.2 Storage and Disposition

Atmospheric Releases and Resulting Impacts to the Public. Total site radiological impacts during operation of storage or disposition facilities can be found by adding the impacts resulting from No Action facilities to the incremental impacts resulting from storage or disposition facilities. For example, to determine the radiological impact for the addition of the AP600 reactor at ORR, the No Action facilities doses would be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases for the storage and disposition facilities are given in Section M.2.3. Tables M.2.8–5 and M.2.8–6 present the atmospheric radiological impacts by alternative facility.

The annual dose associated with the different alternative facilities range from $9.4x10^{-8}$ to 4.8 mrem to the maximally exposed member of the public and from $1.8x10^{-6}$ to 5.1 person-rem to the 80-km (50 mi) population in the year 2030. The associated health effects from annual operations are included in both tables.

Liquid Releases and Resulting Impacts to the Public. There are two disposition technologies that would release liquid discharges to the surface water surrounding ORR. These are the large and small evolutionary Advanced LWRs. The liquid releases for these technologies are given in Section M.2.3. As an example of determining the total site liquid radiological impact associated with the addition of an AP600 reactor at ORR, the No Action liquid doses must be summed with the AP600 reactor liquid doses. Tables M.2.8–7 and M.2.8–8 present the liquid radiological impacts for the applicable alternative facilities.

No change was reported in liquid radioactive releases due to the upgraded or new HEU storage facilities for continued HEU storage at ORR above those radioactive releases already included in No Action. Therefore, there are no changes in dose to the public from the upgraded or new HEU storage facilities at ORR.

The annual incremental doses associated with the different LWR's that have liquid releases range from 0.060 to 0.54 mrem to the maximally exposed member of the public, and range from 0.078 to 0.50 person-rem to the downstream population in 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the changes in impacts from the storage or disposition facilities to determine the impacts from total site operations, refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.9 RADIOLOGICAL IMPACTS AT SAVANNAH RIVER SITE

This section presents the radiological impacts of the various storage and disposition alternatives at SRS. Section M.2.9.1 presents the radiological releases and resulting impacts from facilities associated with No Action. Section M.2.9.2 presents the radiological releases and resulting impacts from the various alternatives.

For purposes of radiological impact modeling, SRS was divided into thirteen separate areas which would release radioactivity in 2005. All potential release points in each area were aggregated into a single release point. Table M.2.9–1 presents the characteristics of each of the release points including location, release height, and minimum distance and annual average dispersion to the site boundary in each of 16 directions. In order to calculate the maximum site boundary dose (that is, the dose ultimately incurred to the site MEI), the dose from each release point to the "maximum receptor" (that is, potential MEI) associated with each of the other release points has been calculated. For example, the dose resulting from releases from F-, H-, S-Areas, the K- and L-Reactors and other storage and disposition alternatives, has been determined for the maximum receptor from the Savannah River Technology Center Laboratory in A-Area. Figure M.2.9–1 illustrates the location of each maximum receptor in relation to each release point. The maximum site boundary dose (that is, the dose ultimately incurred to the site MEI) is then determined by the maximum dose to one of these maximum receptors. Table M.2.9–2 presents the direction, distance, and atmospheric dispersion from each release point to each of the maximum receptors. For further clarification on the definition of the "maximum receptor," refer to Section M.2.2.2. Annual radiological releases were assumed to remain constant during the full operational period.

Descriptions of population and foodstuffs distributions centered on each release area are provided in a Health Risk Data report, October, 1996. The joint frequency distribution used for the dose assessment was based on the meteorological measurements for 1985 from the meteorological tower at SRS at the 61-m (201-ft) height and is contained in the Health Risk Data report.

Doses given in this section are associated with 1 year of operation because regulatory standards are given as annual limits. The health effects are presented on an annual basis in the tables and for the projected operational period in the text. Tables M.2.9–3 through M.2.9–6 include the radiological impacts to the public from both atmospheric releases and from using the surface water for No Action and the storage and disposition alternatives.

Table M.2.9–1. Release Point Characteristics, Direction, Distance, and Atmospheric Dispersion at the Savannah River Site Boundary

Release Point[a]	A-Area	HEU Storage	C-Area	D-Area	LWR Site	F-Area	MOX Fuel Fab
Latitude	33°20' 24.303"	33°17' 44.436"	33°14' 59.126"	33°12' 18.645"	33°15' 26.202"	33°17' 11.230"	33°14' 34.932"
Longitude	-81°44' 6.652"	-81°37' 3.675"	-81°40' 37.760"	-81°44' 14.929"	-81°38' 14.347"	-81°40' 34.560"	-81°34' 49.733"
Release Height	31 m	10 m	61 m	16 m	10 m	61 m	10 m

	Distance and Atmospheric Dispersion at Site Boundary													
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	1,895	$7.3x10^{-7}$	11,484	$2.1x10^{-7}$	14,591	$3.6x10^{-8}$	14,804	$1.2x10^{-7}$	15,162	$1.5x10^{-7}$	10,898	$4.8x10^{-8}$	17,092	$1.2x10^{-7}$
NNE	3,252	$5.4x10^{-7}$	11,609	$2.5x10^{-7}$	17,178	$3.7x10^{-8}$	20,525	$9.3x10^{-8}$	16,006	$1.6x10^{-7}$	12,665	$5.0x10^{-8}$	15,559	$1.7x10^{-7}$
NE	5,443	$3.4x10^{-7}$	13,248	$2.4x10^{-7}$	20,171	$3.3x10^{-8}$	25,502	$8.1x10^{-8}$	17,442	$1.7x10^{-7}$	14,770	$4.5x10^{-8}$	12,020	$2.7x10^{-7}$
ENE	12,398	$1.5x10^{-7}$	13,622	$2.6x10^{-7}$	18,137	$4.6x10^{-8}$	22,616	$1.1x10^{-7}$	14,346	$2.4x10^{-7}$	18,525	$4.5x10^{-8}$	8,089	$5.3x10^{-7}$
E	21,471	$8.7x10^{-8}$	12,267	$3.4x10^{-7}$	16,523	$5.7x10^{-8}$	21,665	$1.3x10^{-7}$	12,854	$3.2x10^{-7}$	17,118	$5.5x10^{-8}$	7,520	$6.7x10^{-7}$
ESE	23,860	$5.4x10^{-8}$	12,030	$2.5x10^{-7}$	17,942	$3.7x10^{-8}$	16,442	$1.3x10^{-7}$	15,287	$1.8x10^{-7}$	16,943	$4.0x10^{-8}$	9,794	$3.3x10^{-7}$
SE	27,210	$2.6x10^{-8}$	15,615	$1.0x10^{-7}$	15,532	$2.2x10^{-8}$	14,573	$8.8x10^{-8}$	15,156	$1.0x10^{-7}$	19,771	$1.7x10^{-8}$	10,298	$1.8x10^{-7}$
SSE	25,918	$1.8x10^{-8}$	17,503	$5.6x10^{-8}$	15,180	$1.7x10^{-8}$	9,140	$1.1x10^{-7}$	14,542	$7.2x10^{-8}$	18,933	$1.4x10^{-8}$	10,942	$1.1x10^{-7}$
S	14,851	$3.5x10^{-8}$	18,113	$5.5x10^{-8}$	14,871	$1.6x10^{-8}$	6,536	$1.7x10^{-7}$	14,883	$7.1x10^{-8}$	18,516	$1.3x10^{-8}$	11,773	$9.8x10^{-8}$
SSW	7,325	$1.2x10^{-7}$	20,688	$6.5x10^{-8}$	13,136	$2.8x10^{-8}$	5,091	$3.4x10^{-7}$	16,175	$9.1x10^{-8}$	15,467	$2.4x10^{-8}$	13,372	$1.2x10^{-7}$
SW	5,305	$3.1x10^{-7}$	16,729	$1.4x10^{-7}$	9,329	$6.9x10^{-8}$	2,584	$1.4x10^{-6}$	14,672	$1.7x10^{-7}$	11,525	$5.6x10^{-8}$	17,355	$1.3x10^{-7}$
WSW	3,421	$5.8x10^{-7}$	15,252	$1.9x10^{-7}$	9,272	$7.7x10^{-8}$	1,990	$2.3x10^{-6}$	12,907	$2.4x10^{-7}$	9,645	$7.4x10^{-8}$	17,206	$1.6x10^{-7}$
W	2,580	$6.0x10^{-7}$	14,818	$1.6x10^{-7}$	9,879	$5.7x10^{-8}$	2,217	$1.6x10^{-6}$	13,125	$1.9x10^{-7}$	9,416	$6.0x10^{-8}$	17,678	$1.3x10^{-7}$
WNW	1,743	$6.8x10^{-7}$	13,150	$1.5x10^{-7}$	9,583	$4.7x10^{-8}$	2,676	$9.8x10^{-7}$	13,373	$1.4x10^{-7}$	9,847	$4.6x10^{-8}$	18,889	$8.9x10^{-8}$
NW	1,603	$5.6x10^{-7}$	12,226	$1.3x10^{-7}$	11,859	$2.9x10^{-8}$	7,920	$1.8x10^{-7}$	14,281	$1.0x10^{-7}$	9,448	$3.6x10^{-8}$	18,982	$7.1x10^{-8}$
NNW	1,385	$6.3x10^{-7}$	11,505	$1.4x10^{-7}$	12,763	$2.7x10^{-8}$	7,897	$1.9x10^{-7}$	14,678	$1.0x10^{-7}$	9,972	$3.5x10^{-8}$	18,119	$7.7x10^{-8}$

Table M.2.9–1. Release Point Characteristics, Direction, Distance, and Atmospheric Dispersion at the Savannah River Site Boundary—Continued

Release Point[a]	H-Area		K-Area		L-Area		M-Area		P-Area		S-Area	
Latitude	33°17' 10.880"		33°12' 42.145"		33°12' 38.484"		33°20' 17.321"		33°13' 42.293"		33°17' 42.592"	
Longitude	-81°38' 25.118"		-81°39' 49.356"		-81°37' 26.480"		-81°44' 15.593"		-81°34' 53.420"		-81°38' 34.989"	
Release Height	61 m		61 m		61 m		10 m		61 m		10 m	
	Distance and Atmospheric Dispersion at Site Boundary											
Direction	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)	Distance (m)	Chi/Q (s/m^3)
N	12,288	$4.3x10^{-8}$	19,103	$2.7x10^{-8}$	20,707	$2.5x10^{-8}$	1,764	$2.9x10^{-6}$	18,709	$2.8x10^{-8}$	11,294	$2.2x10^{-7}$
NNE	12,852	$4.9x10^{-8}$	21,410	$2.9x10^{-8}$	21,148	$2.9x10^{-8}$	2,980	$1.7x10^{-6}$	16,156	$3.9x10^{-8}$	11,975	$2.4x10^{-7}$
NE	14,883	$4.5x10^{-8}$	21,710	$3.1x10^{-8}$	15,504	$4.3x10^{-8}$	5,744	$7.6x10^{-7}$	10,712	$6.2x10^{-8}$	14,232	$2.2x10^{-7}$
ENE	15,959	$5.2x10^{-8}$	15,635	$5.4x10^{-8}$	12,053	$7.0x10^{-8}$	12,796	$2.8x10^{-7}$	7,832	$1.0x10^{-7}$	15,664	$2.2x10^{-7}$
E	14,047	$6.7x10^{-8}$	15,628	$6.0x10^{-8}$	13,327	$7.1x10^{-8}$	21,924	$1.6x10^{-7}$	7,757	$1.2x10^{-7}$	14,622	$2.7x10^{-7}$
ESE	13,688	$4.9x10^{-8}$	13,430	$5.0x10^{-8}$	11,163	$6.1x10^{-8}$	24,035	$9.8x10^{-8}$	9,846	$6.9x10^{-8}$	14,219	$2.0x10^{-7}$
SE	17,629	$2.0x10^{-8}$	11,432	$3.0x10^{-8}$	9,888	$3.5x10^{-8}$	26,982	$4.9x10^{-8}$	9,253	$3.7x10^{-8}$	18,437	$8.1x10^{-8}$
SSE	17,662	$1.5x10^{-8}$	10,837	$2.5x10^{-8}$	9,295	$2.9x10^{-8}$	25,603	$3.4x10^{-8}$	9,658	$2.8x10^{-8}$	18,667	$5.1x10^{-8}$
S	18,109	$1.3x10^{-8}$	11,120	$2.1x10^{-8}$	9,588	$2.5x10^{-8}$	14,346	$7.5x10^{-8}$	10,160	$2.4x10^{-8}$	19,114	$5.1x10^{-8}$
SSW	18,481	$2.0x10^{-8}$	10,680	$3.5x10^{-8}$	12,155	$3.1x10^{-8}$	7,012	$2.8x10^{-7}$	11,769	$3.2x10^{-8}$	19,045	$7.3x10^{-8}$
SW	14,355	$4.4x10^{-8}$	10,612	$6.1x10^{-8}$	12,500	$5.1x10^{-8}$	5,099	$7.2x10^{-7}$	15,824	$4.0x10^{-8}$	14,549	$1.7x10^{-7}$
WSW	14,212	$5.0x10^{-8}$	9,142	$7.8x10^{-8}$	13,517	$5.3x10^{-8}$	3,289	$1.6x10^{-6}$	16,741	$4.2x10^{-8}$	12,874	$2.4x10^{-7}$
W	12,763	$4.4x10^{-8}$	8,855	$6.3x10^{-8}$	12,507	$4.5x10^{-8}$	2,500	$1.9x10^{-6}$	16,724	$3.3x10^{-8}$	12,465	$2.0x10^{-7}$
WNW	12,643	$3.6x10^{-8}$	12,325	$3.6x10^{-8}$	15,669	$2.8x10^{-8}$	2,277	$1.7x10^{-6}$	18,799	$2.3x10^{-8}$	11,487	$1.7x10^{-7}$
NW	11,889	$2.9x10^{-8}$	13,275	$2.5x10^{-8}$	17,079	$1.9x10^{-8}$	1,659	$2.1x10^{-6}$	20,240	$1.6x10^{-8}$	10,979	$1.5x10^{-7}$
NNW	11,749	$3.0x10^{-8}$	17,092	$2.0x10^{-8}$	19,328	$1.8x10^{-8}$	1,485	$2.5x10^{-6}$	19,686	$1.7x10^{-8}$	10,740	$1.5x10^{-7}$

[a] See Figure M.2.9–1 for location of release points.

Source: HNUS 1996a.

Table M.2.9–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Savannah River Site Boundary

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: A-Area			
A-Area and M-Area	N	1,896	7.3×10^{-7}
HEU Storage and S-Area	ESE	23,860	5.4×10^{-8}
C-Area	SSW	14,089	5.6×10^{-8}
D-Area and K-Area	S	15,711	3.3×10^{-8}
LWR Site and MOX Fuel Fab	ESE	24,185	5.3×10^{-8}
F-Area	SSW	8,869	9.9×10^{-8}
H-Area	ESE	24,206	5.3×10^{-8}
L-Area	SE	28,504	2.4×10^{-8}
P-Area	ESE	24,607	5.2×10^{-8}
Release Point: HEU Storage			
A-Area and M-Area	WNW	13,188	1.5×10^{-7}
HEU Storage and S-Area	E	12,267	3.4×10^{-7}
C-Area	WSW	16,571	1.7×10^{-7}
D-Area and K-Area	SW	16,844	1.4×10^{-7}
LWR Site and MOX Fuel Fab	ESE	12,193	2.4×10^{-7}
F-Area	W	15,195	1.6×10^{-7}
H-Area	ESE	12,254	2.4×10^{-7}
L-Area	SE	16,820	9.1×10^{-8}
P-Area	ESE	12,637	2.3×10^{-7}
Release Point: C-Area			
A-Area and M-Area	NNW	13,204	2.6×10^{-8}
HEU Storage and S-Area	ENE	18,313	4.5×10^{-8}
C-Area	WSW	9,273	7.7×10^{-8}
D-Area and K-Area	SW	9,345	6.9×10^{-8}
LWR Site and MOX Fuel Fab	E	16,526	5.7×10^{-8}
F-Area	WNW	9,583	4.7×10^{-8}
H-Area	E	17,287	5.4×10^{-8}
L-Area	ESE	19,141	3.5×10^{-8}
P-Area	E	16,599	5.6×10^{-8}
Release Point: D-Area			
A-Area and M-Area	N	16,816	1.0×10^{-7}
HEU Storage and S-Area	ENE	25,191	9.4×10^{-8}
C-Area	WNW	3,112	8.0×10^{-7}
D-Area and K-Area	WSW	1,991	2.3×10^{-6}
LWR Site and MOX Fuel Fab	ENE	22,651	1.1×10^{-7}
F-Area	NNW	7,949	1.8×10^{-7}
H-Area	ENE	23,721	1.0×10^{-7}
L-Area	E	23,820	1.1×10^{-7}
P-Area	E	22,520	1.2×10^{-7}
Release Point: LWR Site			
A-Area and M-Area	NW	14,555	1.0×10^{-7}
HEU Storage and S-Area	ENE	14,510	2.4×10^{-7}
C-Area	WSW	13,026	2.3×10^{-7}
D-Area and K-Area	WSW	12,917	2.4×10^{-7}

Table M.2.9–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Savannah River Site Boundary—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
LWR Site and MOX Fuel Fab	E	12,855	$3.2x10^{-7}$
F-Area	W	13,125	$1.9x10^{-7}$
H-Area	E	13,531	$3.0x10^{-7}$
L-Area	ESE	16,000	$1.7x10^{-7}$
P-Area	E	12,995	$3.2x10^{-7}$
Release Point: F-Area			
A-Area and M-Area	NW	9,759	$3.5x10^{-8}$
HEU Storage and S-Area	E	17,703	$5.3x10^{-8}$
C-Area	SW	11,589	$5.5x10^{-8}$
D-Area and K-Area	SW	12,260	$5.2x10^{-8}$
LWR Site and MOX Fuel Fab	ESE	16,985	$4.0x10^{-8}$
F-Area	WSW	9,646	$7.4x10^{-8}$
H-Area	E	17,349	$5.4x10^{-8}$
L-Area	ESE	20,708	$3.2x10^{-8}$
P-Area	ESE	17,266	$3.9x10^{-8}$
Release Point: MOX Fuel Fab			
A-Area and M-Area	NW	19,432	$6.9x10^{-8}$
HEU Storage and S-Area	ENE	10,158	$3.9x10^{-7}$
C-Area	W	17,750	$1.3x10^{-7}$
D-Area and K-Area	WSW	17,210	$1.6x10^{-7}$
LWR Site and MOX Fuel Fab	E	7,538	$6.7x10^{-7}$
F-Area	W	18,577	$1.2x10^{-7}$
H-Area	ENE	7,502	$5.9x10^{-7}$
L-Area	ESE	10,573	$3.0x10^{-7}$
P-Area	E	7,565	$6.6x10^{-7}$
Release Point: H-Area			
A-Area and M-Area	NW	12,076	$2.8x10^{-8}$
HEU Storage and S-Area	E	14,356	$6.6x10^{-8}$
C-Area	WSW	14,239	$5.0x10^{-8}$
D-Area and K-Area	SW	14,567	$4.3x10^{-8}$
LWR Site and MOX Fuel Fab	ESE	13,766	$4.9x10^{-8}$
F-Area	W	12,939	$4.3x10^{-8}$
H-Area	E	14,047	$6.7x10^{-8}$
L-Area	SE	17,852	$1.9x10^{-8}$
P-Area	ESE	14,102	$4.8x10^{-8}$
Release Point: K-Area			
A-Area and M-Area	NNW	17,560	$2.0x10^{-8}$
HEU Storage and S-Area	ENE	18,629	$4.5x10^{-8}$
C-Area	W	9,755	$5.8x10^{-8}$
D-Area and K-Area	W	8,871	$6.3x10^{-8}$
LWR Site and MOX Fuel Fab	ENE	15,793	$5.3x10^{-8}$
F-Area	WNW	12,336	$3.6x10^{-8}$
H-Area	ENE	16,942	$4.9x10^{-8}$
L-Area	E	17,014	$5.5x10^{-8}$
P-Area	E	15,629	$6.0x10^{-8}$

Table M.2.9–2. Direction, Distance, and Meteorological Dispersion to Various Maximum Individual Receptors at the Savannah River Site Boundary—Continued

Maximum Receptor For	Direction	Distance (m)	Atmospheric Dispersion Chi/Q (s/m^3)
Release Point: L-Area			
A-Area and M-Area	NNW	19,433	$1.8x10^{-8}$
HEU Storage and S-Area	NE	15,504	$4.3x10^{-8}$
C-Area	W	13,455	$4.2x10^{-8}$
D-Area and K-Area	W	12,529	$4.5x10^{-8}$
LWR Site and MOX Fuel Fab	ENE	12,290	$6.8x10^{-8}$
F-Area	WNW	15,677	$2.8x10^{-8}$
H-Area	ENE	13,557	$6.2x10^{-8}$
L-Area	E	13,327	$7.1x10^{-8}$
P-Area	ENE	12,058	$7.0x10^{-8}$
Release Point: M-Area			
A-Area and M-Area	N	2,078	$2.3x10^{-6}$
HEU Storage and S-Area	ESE	24,035	$9.8x10^{-8}$
C-Area	SSW	13,829	$1.1x10^{-7}$
D-Area and K-Area	S	15,468	$6.8x10^{-8}$
LWR Site and MOX Fuel Fab	ESE	24,305	$9.6x10^{-8}$
F-Area	SSW	8,574	$2.2x10^{-7}$
H-Area	ESE	24,347	$9.6x10^{-8}$
L-Area	SE	28,576	$4.5x10^{-8}$
P-Area	ESE	24,719	$9.4x10^{-8}$
Release Point: P-Area			
A-Area and M-Area	NW	20,454	$1.6x10^{-8}$
HEU Storage and S-Area	NE	11,137	$6.0x10^{-8}$
C-Area	W	17,456	$3.2x10^{-8}$
D-Area and K-Area	W	16,737	$3.3x10^{-8}$
LWR Site and MOX Fuel Fab	ENE	7,915	$1.0x10^{-7}$
F-Area	WNW	18,800	$2.3x10^{-8}$
H-Area	ENE	9,137	$9.1x10^{-8}$
L-Area	ESE	9,953	$6.8x10^{-8}$
P-Area	E	7,758	$1.2x10^{-7}$
Release Point: S-Area			
A-Area and M-Area	NW	11,264	$1.4x10^{-7}$
HEU Storage and S-Area	E	14,623	$2.7x10^{-7}$
C-Area	SW	14,591	$1.7x10^{-7}$
D-Area and K-Area	SW	15,046	$1.6x10^{-7}$
LWR Site and MOX Fuel Fab	ESE	14,336	$1.9x10^{-7}$
F-Area	WSW	12,875	$2.4x10^{-7}$
H-Area	ESE	14,510	$1.9x10^{-7}$
L-Area	S	18,625	$8.0x10^{-8}$
P-Area	ESE	14,719	$1.9x10^{-7}$

Source: HNUS 1996a.

Table M.2.9–3. Doses and Resulting Health Effects to the Maximally Exposed Individual From Atmospheric Releases Associated With Annual Normal Operation at Savannah River Site

Alternative/Facility	Dose by Pathway (mrem)				Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	4.4×10^{-2}	3.9×10^{-1}	1.1×10^{-7}	3.6×10^{-5}	4.2×10^{-1}	1.4×10^{-1}	2.1×10^{-7}
Upgraded Storage Facility[b]	[c]	[c]	[c]	[c]	6.2×10^{-6}	2.2×10^{-6}	3.1×10^{-12}
Consolidated Storage Facility	1.4×10^{-5}	2.5×10^{-8}	5.5×10^{-15}	1.1×10^{-11}	1.4×10^{-5}	4.7×10^{-6}	7.0×10^{-12}
Collocated Storage Facilities	1.4×10^{-5}	2.4×10^{-8}	5.7×10^{-15}	1.7×10^{-11}	1.4×10^{-5}	4.7×10^{-6}	7.0×10^{-12}
Pit Disassembly/Conversion Facility	1.6×10^{-3}	3.5×10^{-5}	9.3×10^{-12}	1.4×10^{-8}	1.6×10^{-3}	5.4×10^{-4}	8.0×10^{-10}
Pu Conversion Facility	1.0×10^{-3}	1.9×10^{-6}	4.4×10^{-13}	9.1×10^{-10}	1.0×10^{-3}	3.4×10^{-4}	5.0×10^{-10}
MOX Fuel Fabrication Facility	1.5×10^{-3}	2.5×10^{-6}	5.6×10^{-13}	2.7×10^{-9}	1.5×10^{-3}	5.0×10^{-4}	7.5×10^{-10}
Ceramic Immobilization Facility (Immobilized Disposition)	1.8×10^{-7}	3.2×10^{-10}	7.0×10^{-17}	1.4×10^{-13}	1.8×10^{-7}	6.0×10^{-8}	9.0×10^{-14}
Deep Borehole Complex (Direct Disposition)	2.7×10^{-8}	3.9×10^{-10}	1.0×10^{-16}	1.6×10^{-13}	2.8×10^{-8}	9.4×10^{-9}	1.4×10^{-14}
Deep Borehole Complex (Immobilized Disposition)	3.4×10^{-8}	5.9×10^{-10}	1.5×10^{-16}	2.3×10^{-13}	3.4×10^{-8}	1.1×10^{-8}	1.7×10^{-14}
Vitrification Facility	7.1×10^{-5}	4.9×10^{-6}	1.4×10^{-9}	7.7×10^{-7}	7.7×10^{-5}	2.6×10^{-5}	3.9×10^{-11}
Ceramic Immobilization Facility (Ceramic Immobilization)	2.0×10^{-7}	9.5×10^{-7}	2.8×10^{-10}	1.5×10^{-7}	1.3×10^{-6}	4.4×10^{-7}	6.5×10^{-13}
Advanced Boiling Water Reactor	3.1×10^{-3}	2.3×10^{-1}	2.9×10^{-2}	3.7×10^{-3}	2.6×10^{-1}	8.7×10^{-2}	1.3×10^{-7}
CE System 80+ Reactor	8.1×10^{-3}	2.0×10^{-1}	4.2×10^{-3}	1.0×10^{-4}	2.1×10^{-1}	7.0×10^{-2}	1.1×10^{-7}
[Text deleted.]							
AP600 Reactor	1.8×10^{-3}	1.5×10^{-1}	1.4×10^{-2}	1.1×10^{-3}	1.6×10^{-1}	5.4×10^{-2}	8.0×10^{-8}
RESAR-90 Reactor	6.5×10^{-3}	2.1×10^{-1}	5.9×10^{-3}	1.2×10^{-3}	2.3×10^{-1}	7.7×10^{-2}	1.2×10^{-7}

[a] Individual annual natural background radiation dose is equal to 298 mrem.

[b] Dose and health effect results are based on a capacity of 5,000 Pu storage positions in the APSF (SR DOE 1995e). Because the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative and the Upgrade With RFETS Non-Pit Pu Subalternative both call for fewer than 5,000 Pu storage positions in the APSF, dose and health effects for these two subalternatives would be less. The dose shown here is for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative. The dose for the Upgrade With RFETS Non-Pit Pu Subalternative would be slightly less, and would be below detection limits.

[c] Number reflected as a component in the Committed Effected Dose Equivalent.

Source: HNUS 1996a.

Table M.2.9–4. Doses and Resulting Health Effects to the Population Within 80 Kilometers of Savannah River Site From Atmospheric Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)				Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer
	Inhalation	Ingestion	Plume Immersion	Ground Shine			
No Action (Total Site)	3.9	3.6×10^{1}	2.5×10^{-5}	5.1×10^{-3}	40×10^{1}	1.5×10^{-2}	2.0×10^{-2}
Upgraded Storage Facility[b]	c	c	c	c	2.9×10^{-4}	1.1×10^{-7}	1.5×10^{-7}
Consolidated Storage Facility	9.2×10^{-4}	2.6×10^{-6}	3.6×10^{-13}	7.4×10^{-10}	9.2×10^{-4}	3.5×10^{-7}	4.6×10^{-7}
Collocated Storage Facilities	8.8×10^{-4}	2.7×10^{-6}	3.6×10^{-13}	1.1×10^{-9}	8.8×10^{-4}	3.3×10^{-7}	4.4×10^{-7}
Pit Disassembly/Conversion Facility	0.10	3.6×10^{-3}	6.2×10^{-10}	9.1×10^{-7}	0.11	4.1×10^{-5}	5.5×10^{-5}
Pu Conversion Facility	6.6×10^{-2}	2.0×10^{-4}	2.8×10^{-11}	5.9×10^{-8}	6.6×10^{-2}	2.5×10^{-5}	3.3×10^{-5}
MOX Fuel Fabrication Facility	4.4×10^{-2}	1.6×10^{-4}	1.6×10^{-11}	7.8×10^{-8}	4.4×10^{-2}	1.7×10^{-5}	2.2×10^{-5}
Ceramic Immobilization Facility (Immobilized Disposition)	1.2×10^{-5}	3.2×10^{-8}	4.6×10^{-15}	9.2×10^{-12}	1.2×10^{-5}	4.5×10^{-9}	6.0×10^{-9}
Deep Borehole Complex (Direct Disposition)	1.7×10^{-6}	4.7×10^{-8}	6.6×10^{-15}	9.8×10^{-12}	1.7×10^{-6}	6.4×10^{-10}	8.5×10^{-10}
Deep Borehole Complex (Immobilized Disposition)	2.1×10^{-6}	6.8×10^{-8}	9.5×10^{-15}	1.5×10^{-11}	2.2×10^{-6}	8.3×10^{-10}	1.1×10^{-9}
Vitrification Facility	4.7×10^{-3}	2.3×10^{-4}	9.1×10^{-8}	5.1×10^{-5}	5.0×10^{-3}	1.9×10^{-6}	2.5×10^{-6}
Ceramic Immobilization Facility (Ceramic Immobilization)	1.3×10^{-5}	4.4×10^{-5}	1.9×10^{-8}	1.0×10^{-5}	6.7×10^{-5}	2.5×10^{-8}	3.4×10^{-8}
Advanced Boiling Water Reactor	1.8×10^{-1}	30	1.2	1.9×10^{-1}	32	1.2×10^{-2}	1.6×10^{-2}
CE System 80+ Reactor	5.1×10^{-1}	27	1.8×10^{-1}	5.9×10^{-3}	28	1.1×10^{-2}	1.4×10^{-2}
[Text deleted.]							
AP600 Reactor	1.1×10^{-1}	23	6.5×10^{-1}	6.5×10^{-2}	24	9.0×10^{-3}	1.2×10^{-2}
RESAR-90 Reactor	4.0×10^{-1}	29	3.0×10^{-1}	7.5×10^{-2}	29	1.1×10^{-2}	1.5×10^{-2}

[a] Total dose to the population within 80 km from natural background radiation in year 2030 is equal to 266,000 person-rem.

[b] Dose and health effect results are based on a capacity of 5,000 Pu storage positions in the APSF (SR DOE 1995e). Because the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative and the Upgrade With RFETS Non-Pit Pu Subalternative both call for fewer than 5,000 Pu storage positions in the APSF, dose and health effects for these two subalternatives would be less. The dose shown here is for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative. The dose for the Upgrade With RFETS Non-Pit Pu Subalternative would be slightly less, and would be below detection limits.

[c] Number reflected as a component in the Committed Effective Dose Equivalent.

Source: HNUS 1996a.

Table M.2.9–5. Doses and Resulting Health Effects to the Maximally Exposed Individual From Liquid Releases Associated With Annual Normal Operation at Savannah River Site

Alternative/Facility	Dose by Pathway (mrem)						Committed Effective Dose Equivalent (mrem)	Percent of Background[a]	Estimated 1-Year Fatal Cancer Risk
	Fish Ingestion	Other Food Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	0.27	8.1×10^{-2}	2.3×10^{-2}	2.0×10^{-6}	4.0×10^{-6}	5.9×10^{-4}	0.37	0.13	1.9×10^{-7}
Upgrade Storage Facility[b]	[c]	[c]	[c]	[c]	[c]	[c]	6.1×10^{-7}	2.1×10^{-6}	3.0×10^{-13}
Advanced Boiling Water Reactor	1.4×10^{-2}	4.3×10^{-4}	1.3×10^{-4}	6.1×10^{-7}	1.2×10^{-6}	1.3×10^{-4}	1.5×10^{-2}	4.9×10^{-3}	7.3×10^{-9}
CE System 80+	4.7×10^{-2}	2.9×10^{-3}	7.9×10^{-4}	2.1×10^{-6}	4.1×10^{-6}	3.5×10^{-4}	5.2×10^{-2}	1.7×10^{-2}	2.6×10^{-8}
[Text deleted.]									
AP600 Reactor	6.1×10^{-2}	4.9×10^{-3}	1.4×10^{-3}	2.0×10^{-6}	3.9×10^{-6}	3.7×10^{-4}	6.7×10^{-2}	2.3×10^{-2}	3.4×10^{-8}
RESAR-90 Reactor	4.3×10^{-2}	6.1×10^{-3}	1.8×10^{-3}	1.9×10^{-6}	3.8×10^{-6}	2.1×10^{-4}	5.1×10^{-2}	1.7×10^{-2}	2.5×10^{-8}

[a] Individual annual natural background radiation dose equal to 298 mrem.

[b] Dose and health effect results are based on a capacity of 5,000 Pu storage positions in the APSF (SR DOE 1995e). Because the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative and the Upgrade With RFETS Non-Pit Pu Subalternative both call for fewer than 5,000 Pu storage positions in the APSF, dose and health effects for these two subalternatives would be less. The dose shown here is for the Upgrade With All Or Some RFETS Pu and LANL Pu Subalternative. The dose for the upgrade with RFETS Non-Pit Pu Subalternative would be slightly less.

[c] Number reflected as a component in the Committed Effective Dose Equivalent.

Source: HNUS 1996a.

Table M.2.9–6. Doses and Resulting Health Effects to the Population Downstream of Savannah River Site From Liquid Releases Associated With Normal Operation in 2030

Alternative/Facility	Dose by Pathway (person-rem)					Committed Effective Dose Equivalent (person-rem)	Percent of Background[a]	Estimated 1-Year Fatal Cancers
	Fish Ingestion	Drinking Water	Boating	Swimming	Shoreline			
No Action (Total Site)	9.0×10^{-1}	2.7	2.2×10^{-5}	6.4×10^{-6}	1.2×10^{-3}	3.6	1.3×10^{-3}	1.8×10^{-3}
Upgrade Storage Facility[b]	c	c	c	c	c	1.0×10^{-5}	3.5×10^{-9}	5.0×10^{-9}
Advanced Boiling Water Reactor	8.2×10^{-2}	1.4×10^{-2}	6.8×10^{-6}	2.0×10^{-6}	2.4×10^{-4}	9.6×10^{-2}	3.4×10^{-5}	4.8×10^{-5}
CE System 80+	2.3×10^{-1}	9.2×10^{-2}	2.3×10^{-5}	6.7×10^{-6}	6.7×10^{-4}	3.2×10^{-1}	1.1×10^{-4}	1.6×10^{-4}
[Text deleted.]								
AP600 Reactor	2.3×10^{-1}	1.6×10^{-1}	2.2×10^{-5}	6.2×10^{-6}	7.2×10^{-4}	3.9×10^{-1}	1.4×10^{-4}	2.0×10^{-4}
RESAR-90 Reactor	1.6×10^{-1}	2.0×10^{-1}	2.1×10^{-5}	6.2×10^{-6}	4.1×10^{-4}	3.6×10^{-1}	1.3×10^{-4}	1.8×10^{-4}

[a] Natural background radiation dose to the population within 80 km plus the people who use the Savannah River for drinking water at the Port Wentworth and Beaufort-Jasper location is: 285,000 person-rem in the year 2030.

[b] Dose and health effect results are based on a capacity of 5,000 Pu storage positions in the APSF (SR DOE 1995e). Because the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative and the Upgrade With RFETS Non-Pit Pu Subalternative both call for fewer than 5,000 Pu storage positions in the APSF, dose and health effects for these two subalternatives would be less. The dose shown here is for the Upgrade With All or Some RFETS Pu and LANL Pu Subalternative. The dose for the Upgrade With RFETS Non-Pit Pu Subalternative would be slightly less.

[c] Number reflected as a component in the Committed Effective Dose Equivalent.

Source: HNUS 1996a.

M.2.9.1 No Action

Atmospheric Releases and Resulting Impacts to the Public. For No Action, all of the areas have radioactive releases in to the atmosphere from normal operation. Table M.2.9.1–1 presents the estimated annual atmospheric radioactive releases.

Tables M.2.9–3 and M.2.9–4 include the atmospheric radiological impacts to the maximally exposed member of the public and the offsite population within 80 km (50 mi), respectively. The MEI would receive an annual dose of 0.42 mrem. An estimated fatal cancer risk of 1.1×10^{-5} would result from 50 years of operation. The population within 80 km (50 mi) would receive a dose of 40 person-rem in 2030 (midlife of operation). An estimated 1.0 fatal cancers would result from 50 years of operation.

Liquid Releases and Resulting Impacts to the Public. For No Action, some areas may have radioactive releases to the offsite surface water from normal operation. Table M.2.9.1–2 presents the estimated annual liquid radioactive releases.

Tables M.2.9–5 and M.2.9–6 include the radiological impacts to the MEI and the offsite populations using water from the Savannah River downstream of SRS to the Atlantic Ocean. The maximally exposed member of the public would receive an annual dose of 0.37 mrem. An estimated fatal cancer risk of 9.3×10^{-6} would result from 50 years of operation. The population would receive a dose of 3.6 person-rem in 2030. An estimated 0.09 fatal cancers would result from 50 years of operation.

Worker Doses. It is projected that in 2005 and beyond, there would be 7,069 badged workers involved in No Action activities. The annual average dose among these workers would be 36 mrem and the annual dose among all these workers would equal 259 person-rem. From 50 years of operation, an estimated fatal cancer risk of 7.2×10^{-4} would result to the average worker and 5.2 fatal cancers could result among all workers.

Table M.2.9.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Savannah River Site (curies)

Isotope	SRTC	K-Reactor	L-Reactor	F-Area		H-Area		RBOF	Tritium Facilities
				Canyon Releases	Waste Management	Canyon Releases	Waste Management		
H-3	0	3.5×10^{3}	1.9×10^{2}	0	0	0	1.7×10^{0}	0	2.2×10^{4}
C-14	0	0	0	7.4×10^{-3}	0	1.1×10^{-3}	0	0	0
S-35	0	0	0	0	0	0	0	0	0
[Text deleted.]									
Cr-51	0	0	0	0	0	0	0	0	0
Co-60	0	0	0	0	5.9×10^{-9}	0	0	0	0
Ni-63	0	0	0	0	0	0	0	0	0
Se-79	0	0	0	0	0	0	0	0	0
Sr-89	0	0	0	0	0	0	0	0	0
Sr-90	1.2×10^{-5}	1.9×10^{-7}	1.8×10^{-5}	8.1×10^{-4}	0	1.3×10^{-4}	0	0	0
Y-90	0	0	0	0	0	0	0	0	0
Y-91	0	0	0	0	0	0	0	0	0
Zr-95	0	0	0	0	0	0	0	0	0
Nb-95	0	0	0	0	0	0	0	0	0
Tc-99	0	0	0	0	0	0	0	0	0
Ru-106	0	0	4.0×10^{-7}	0	0	0	5.8×10^{-9}	0	0
Sn-126	0	0	0	0	0	0	0	0	0
Sb-125	0	0	0	0	0	0	0	0	0
Te-125m	0	0	0	0	0	0	0	0	0
Te-127m	0	0	0	0	0	0	0	0	0
Te-127	0	0	0	0	0	0	0	0	0
I-129	0	0	0	1.3×10^{-3}	0	1.2×10^{-3}	0	0	0

Table M.2.9.1–1. Annual Atmospheric Radioactive Releases From Normal Operation of No Action at Savannah River Site (curies)—Continued

Isotope	SRTC	K-Reactor	L-Reactor	F-Area Canyon Releases	F-Area Waste Management	H-Area Canyon Releases	H-Area Waste Management	RBOF	Tritium Facilities
I-131	$5.9x10^{-5}$	0	0	$1.5x10^{-6}$	0	$4.3x10^{-5}$	0	0	0
I-133	$2.0x10^{-3}$	0	0	0	0	0	0	0	0
[Text deleted.]									
Xe-135	$3.2x10^{-2}$	0	0	0	0	0	0	0	0
Cs-134	0	0	0	$6.9x10^{-7}$	0	0	$1.1x10^{-7}$	0	0
Cs-135	0	0	0	0	0	0	0	0	0
Cs-137	$1.5x10^{-6}$	$1.1x10^{-7}$	$1.0x10^{-5}$	$2.3x10^{-4}$	$3.8x10^{-6}$	$2.0x10^{-5}$	$2.2x10^{-5}$	$2.1x10^{-7}$	0
Ce-144	0	0	0	0	0	0	0	0	0
Pr-144	0	0	0	0	0	0	0	0	0
Pm-147	0	0	0	0	0	0	0	0	0
Sm-151	0	0	0	0	0	0	0	0	0
Eu-152	0	0	0	0	0	0	0	0	0
Eu-154	0	0	0	0	0	0	0	0	0
Eu-155	0	0	0	0	0	0	0	0	0
U-235	$2.9x10^{-8}$	0	0	$8.8x10^{-4}$	$2.1x10^{-6}$	$4.7x10^{-5}$	0	0	0
Pu-238	$1.0x10^{-8}$	0	0	$1.6x10^{-4}$	$3.2x10^{-7}$	$4.4x10^{-4}$	0	0	0
Pu-239	$9.4x10^{-6}$	$4.4x10^{-9}$	$4.1x10^{-7}$	$4.3x10^{-4}$	$2.6x10^{-7}$	$1.0x10^{-4}$	0	0	0
Pu-240	0	0	0	0	0	0	0	0	0
Pu-241	0	0	0	0	0	0	0	0	0
Am-241	$1.3x10^{-6}$	0	0	$3.1x10^{-5}$	$1.0x10^{-7}$	$4.0x10^{-5}$	0	0	0
Cm-244	$6.8x10^{-6}$	0	0	$2.2x10^{-5}$	0	$3.3x10^{-6}$	0	0	0

Table M.2.9.1–1. Annual Atmospheric Radioactive Releases from Normal Operation of No Action at Savannah River Site (curies)—Continued

Isotope	DWPF	M–Area	CIF	P–Reactor	C–Reactor	D–Area	Diffuse Area
H-3	2.0×10^{1}	0	1.2×10^{3}	1.3×10^{3}	1.5×10^{2}	4.5×10^{2}	4.3×10^{1}
C-14	2.1×10^{-2}	0	0	0	0	0	4.0×10^{-6}
S-35	0	0	0	0	0	0	2.0×10^{-6}
[Text deleted.]							
Cr-51	0	0	1.5×10^{-2}	0	0	0	0
Co-60	6.1×10^{-8}	0	1.4×10^{-4}	0	0	0	3.3×10^{-17}
Ni-63	0	0	0	0	0	0	2.0×10^{-7}
Se-79	8.8×10^{-9}	0	0	0	0	0	0
Sr-89	0	0	6.0×10^{-4}	0	0	0	0
Sr-90	2.3×10^{-5}	8.3×10^{-5}	2.2×10^{-2}	0	0	7.2×10^{-6}	1.1×10^{-4}
Y-90	2.4×10^{-5}	0	7.6×10^{-5}	0	0	0	0
Y-91	0	0	4.5×10^{-4}	0	0	0	0
Zr-95	0	0	4.7×10^{-4}	0	0	0	2.4×10^{-14}
Nb-95	0	0	1.5×10^{-3}	0	0	0	0
Tc-99	3.8×10^{-7}	0	0	0	0	0	0
Ru-106	3.2×10^{-5}	0	1.8×10^{-4}	0	0	0	5.0×10^{-12}
Sn-126	6.9×10^{-8}	0	0	0	0	0	0
Sb-125	6.7×10^{-7}	0	0	0	0	0	7.3×10^{-15}
Te-125m	1.0×10^{-5}	0	0	0	0	0	0
Te-127m	4.5×10^{-9}	0	0	0	0	0	0
Te-127	4.4×10^{-9}	0	0	0	0	0	0
I-129	8.2×10^{-5}	0	0	0	0	0	6.9×10^{-7}
I-131	0	0	0	0	0	0	0
I-133	0	0	0	0	0	0	0
[Text deleted.]							

Table M.2.9.1–1. Annual Atmospheric Radioactive Releases from Normal Operation of No Action at Savannah River Site (curies)—Continued

Isotope	DWPF	M–Area	CIF	P–Reactor	C–Reactor	D–Area	Diffuse Area
Xe-135	0	0	0	0	0	0	0
Cs-134	2.9×10^{-5}	0	0	0	0	0	1.4×10^{-17}
Cs-135	9.4×10^{-7}	0	0	0	0	0	0
Cs-137	4.1×10^{-3}	0	2.4×10^{-4}	0	0	0	4.3×10^{-11}
Ce-144	3.0×10^{-6}	0	2.3×10^{-4}	0	0	0	1.1×10^{-13}
Pr-144	3.1×10^{-6}	0	2.3×10^{-4}	0	0	0	0
Pm-147	7.6×10^{-6}	0	9.1×10^{-4}	0	0	0	0
Sm-151	1.6×10^{-7}	0	0	0	0	0	0
Eu-152	1.4×10^{-9}	0	0	0	0	0	0
Eu-154	2.3×10^{-7}	0	0	0	0	0	3.4×10^{-13}
Eu-155	1.6×10^{-7}	0	0	0	0	0	1.6×10^{-13}
U-235	0	1.6×10^{-5}	0	0	0	0	4.7×10^{-5}
Pu-238	7.9×10^{-7}	0	1.4×10^{-4}	0	0	0	4.6×10^{-12}
Pu-239	7.1×10^{-9}	3.5×10^{-6}	5.2×10^{-7}	0	0	8.4×10^{-7}	4.7×10^{-7}
Pu-240	4.8×10^{-9}	0	0	0	0	0	0
Pu-241	7.7×10^{-7}	0	0	0	0	0	0
Am-241	8.6×10^{-9}	0	0	0	0	0	8.9×10^{-13}
Cm-244	2.7×10^{-8}	0	0	0	0	0	7.3×10^{-12}

Note: SRTC=Savannah River Technology Center; RBOF=Receiving Basin Offsite Fuel.
Source: WSRC 1994d.

Table M.2.9.1–2. Annual Liquid Releases From Normal Operation of No Action at Savannah River Site (curies)

Isotope	Release[a]
H-3	1.3×10^{4}
Sr-90	0.48
I-129	0.022
Cs-137	0.25
Pm-147	7.0×10^{-3}
U-235	1.1×10^{-5}
Pu-239	9.6×10^{-3}

[a] Total Site release.
Source: WSRC 1994d.

M.2.9.2 Storage and Disposition

Atmospheric Releases and Resulting Impacts to the Public. Total site radiological impacts during operation of storage or disposition facilities can be found by adding the impacts resulting from No Action facilities to the changes in impacts resulting from storage or disposition facilities. For example, to determine the radiological impact for the addition of an AP600 reactor at SRS, the No Action facilities doses would be summed with the AP600 reactor doses. Estimated annual atmospheric radioactive releases for the storage and disposition facilities are given in Section M.2.3. Tables M.2.9–3 and M.2.9–4 include the atmospheric radiological impacts by alternative facility.

Virtually, no change is anticipated in radioactive releases due to the upgraded or new Pu storage facilities for continued Pu storage at SRS above those radioactive releases already included in No Action. Therefore, there are no changes in dose to the public from the upgraded or new Pu storage facilities at SRS.

The annual doses from total site operations associated with the different alternative facilities range from 0 to 0.26 mrem to the maximally exposed member of the public and from 0 to 32 person-rem to the 80-km (50-mi) population in 2030. The associated health effects from annual operations are included in both tables.

Liquid Releases and Resulting Impacts to the Public. There are two disposition technologies that would release liquid discharges to the surface water surrounding SRS. These are the large and small evolutionary LWRs. The liquid releases for these two technologies are given in Section M.2.3. As an example of determining the total site liquid radiological impact associated with the addition of an AP600 reactor at SRS, the No Action liquid doses must be summed with the AP600 reactor liquid doses. Table M.2.9–5 and M.2.9–6 present the liquid radiological impacts for the applicable alternative facilities.

The annual doses associated with the different LWRs that have liquid releases range from 0.015 to 0.067 mrem to the maximally exposed member of the public, and range from 0.096 to 0.39 person-rem to the downstream population in 2030. The associated health effects from annual operations are included in both tables.

Worker Doses and Health Effects. For the storage and disposition alternatives, the impacts from the No Action facilities need to be added to the changes in impacts from the storage or disposition facilities to determine the impacts from total site operations (refer to the worker discussion under No Action, above, and to Table M.2.3.2–1).

M.2.10 RADIOLOGICAL IMPACT AT ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

The results of the radiological consequence assessments for the RFETS and the sources of data used in the assessments are given in Section 4.2.7.9.

M.2.11 RADIOLOGICAL IMPACT AT LOS ALAMOS NATIONAL LABORATORY

The results of the radiological consequence assessments the LANL and the source of data used in the assessments are given in Section 4.2.8.9.

M.2.12 DEEP BOREHOLE DISPOSITION GENERIC SITE

The results of the radiological consequence assessments for the generic borehole site are given in Sections 4.3.3.1.9 and 4.3.3.2.2.9. The sources of data used in the assessments are given in Health Physics Data, October 1996.

M.2.13 GENERIC MIXED OXIDE FUEL FABRICATION SITE

The results of the radiological consequence assessments for the generic MOX fuel fabrication facility are given in Section 4.3.5.1.9. The sources of data used in the assessments are given in Health Physics Data, October 1996.

M.2.14 EXISTING LIGHT-WATER REACTOR GENERIC SITE

The results of the radiological consequence assessments for the generic existing light-water reactor facility are given in Section 4.3.5.2.9. The sources of data used in the assessments are given in Health Physics Data, October 1996.

M.2.15 PARTIALLY COMPLETED REACTOR GENERIC SITE

The results of the radiological consequence assessments for the generic partially completed reactor site are given in Section 4.3.5.3.9. The sources of data used in the assessments are given in Health Physics Data, October 1996.

M.3 HAZARDOUS CHEMICAL IMPACTS TO HUMAN HEALTH

M.3.1 BACKGROUND

Two general types of adverse human health effects are assessed for hazardous chemical exposure in this PEIS. These are carcinogenic and non-carcinogenic effects. For this reason, two tables were developed to assist the risk assessor in the evaluation process. Table M.3.2–1, the Table of Chemical Toxicity Profiles, characterizes each chemical in terms of physical properties, potential exposure routes, and the effects on target tissues/organs that might be expected. The risk assessor will use it qualitatively to determine how exposure might occur (exposure route), what tissue or organ system might be affected (for example, central nervous system dysfunction or liver cancer) and whether the chemical might possess other properties affecting its bioavailability in a given matrix (that is, air, water, or soil). Table M.3.3–1, the Table of Exposure Limits, provides the risk assessor with the necessary information to calculate risk or expected effects should an individual be exposed to a hazardous chemical for a long time at low levels (chronic exposure) or to higher concentrations for a short time (acute). Where a dose effect calculation is required (milligram [mg]/kilogram [kg]/day), the Reference Dose (RfD) is applicable, and where an inhalation concentration effect is required, the Reference Concentration (for example, Reference Concentration [RfC] in mg/cubic meter) is applicable for chronic exposures. The Permissible Exposure Limit (PEL) value, which regulates worker's exposures over 8-hour (hr) periods, determines the concentration allowed for occupational exposures that would be without adverse acute effects. Other values, such as the Threshold Limit Value, are presented for the reader's information, because they are prepared by the American Conference of Governmental Industrial Hygienists (ACGIH) for guidance on exposures of 8-hr periods, and can be used to augment PELs or serve as exposure levels in the absence of a PEL. All currently regulated chemicals associated with each site and every hazardous chemical are presented in Table M.3.2–1 and Table M.3.3–1.

It was assumed that under normal operation conditions, members of the public would only receive chronic exposures at low levels in the form of air emissions from a centrally located source term at each site; since hazardous chemicals are not released into surface or ground waters or into soil, inhalation is assumed to be the only route of exposure. However, all chemical quantities are accounted for as air emissions, which are several orders of magnitude greater than by all other possible routes combined. It was further assumed that the MEI member of the public would be at the site boundary and this assumption was used when calculating all public exposures, which under normal operating conditions are expected to be chronic and at very low levels. For worker exposures to hazardous chemicals, it was assumed that individuals were exposed only to low air emission concentrations during an 8-hr day for a 40-hr week for a maximum working lifetime of 40 years. The point of exposure chosen was 100 m (328 ft) from a centrally located source term, since the precise placement of source terms onsite could not be made. Further, it could not be determined where the involved and non-involved workers would be relative to the emission sources.

For every site involved in the analysis, Hazard Indexes (HIs) were calculated for every alternative action relative to the site. The exposure concentrations of hazardous chemicals for the public and the onsite workers were developed using the Industrial Source Complex Short Term Model for point, area, and volume sources. This model, which estimates dispersion of emissions from these sources, has been field tested and recommended by the EPA. The modeled concentrations were compared to the unique RfC and PEL values unique to each chemical to yield Hazard Quotients (HQs) for the public and onsite workers, respectively. The HQs were summed to give the HIs for each alternative action at each site, as well as total HIs (that is, No Action HI + alternative-incremental HI). For cancer risk estimation, the inhaled concentrations were converted to doses in mg/kg/day, which were then multiplied by the slope factors unique to each identified carcinogen. The risks for all carcinogens associated with each alternative (incremental risk) at each site were summed, and the No Action cancer risk for each site was added in order to show the total risk should that alternative action be implemented at a given site. We apply this conservative approach to all sites using the guidance under the *Comprehensive Environmental Response Compensation and Liability Act*, which applies to Superfund sites. The first

assessment in risk analysis is considered a screening step. Under this guidance, if the HI is less than, or equal to 1.0, all non-cancer exposure values meet Occupational Safety and Health Administration (OSHA) standards; if the cancer risk is less than or equal to $1.0x10^{-6}$, no further analysis is done. A cancer risk of $1.0x10^{-6}$ from other sources cannot be distinguished from the cancer risk for an individual member of the general population.

M.3.2 CHEMICAL TOXICITY PROFILES

Table M.3.2–1 provides the reader with pertinent facts about each chemical that is included in this PEIS's human health risk assessment. This includes the Chemical Abstracts Service number, which aids in a search for information available on any specific chemical and ensures a positive identity regardless of which name or synonym is used. It also contains physical information (that is, solubility, vapor pressure, and flammability) as well as presenting incompatibility data that is useful in determining whether a hazard might exist and the nature of the hazard. The route of exposure, target organs/tissues, and carcinogenicity provide an abbreviated summary on how individuals might get exposed, what body functions could be affected, and whether chronic exposure could lead to increased cancer incidence in an exposed population.

Table M.3.2–1. Chemical Toxicity Profiles

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Acetaldehyde	75-07-0	Miscible[d]	740 mm[d]	Class IA Flammable liquid[d]	Strong oxidizers, acids, bases, alcohols, ammonia, amines, phenols, ketones, HCN, H_2S (Prolonged contact with air may form peroxides that may explode: Easily polymerizes)[d]	Inh, ing con[d]	Eyes, skin, resp sys, kidneys, repro sys (In animals: nasal cancer)[d]	EPA Group B2[e]
Acetic acid	64-19-7	Miscible[d]	11 mm[d]	Class II Combustible liquid[d]	Strong oxidizers, strong caustics, corrosive to metals[d]	Inh, con[d]	Eyes, skin, resp sys, teeth[d]	Not Classified
Acetone	67-64-1	Miscible[d]	180 mm[d]	Class IB[d]	Oxidizers, acids[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	EPA Group D[e]
Acetonitrile	75-05-8	Miscible[d]	73 mm[d]	Class IB[d]	Strong oxidizers[d]	Inh, abs, ing, con[d]	Resp sys, CVS, CNS, liver, kidneys[d]	Not Classified
Acetylene	74-86-2	2%[d]	44.2 atm[d]	Flammable gas[d]	Zinc; Oxygen and other oxidizing agents such as halogens[d]	Inh, con (liq)[d]	CNS, resp sys[d]	Not Classified
Aluminum	7429-90-5	Insoluble[d]	0 mm (approx)[d]	Combustible solid, finely divided dust is easily ignited[d]	Strong oxidizers, acids, halogenated hydrocarbons[d]	Inh, con[d]	Eyes, skin, resp sys[d]	Not Classified
Aluminum welding fumes	None	Insoluble[d]	0 mm (approx)[d]	Noncombustible solid, but dust may form explosive mixtures in air[d]	Chlorine, trifluoride, hot chlorinated rubber, acids, oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Ammonia	7664-41-7	34%[d]	8.5 atm[d]	Treat as a flammable gas[d]	Strong oxidizers, acids, halogens, salts of Ag and Zn[d]	Inh, ing (soln), con (soln/liq)[d]	Eyes, skin, resp sys[d]	EPA Group D[e]
Ammonium hydroxide	1336-21-6	Soluble[f]	None Found	None Found	Strong oxidizers, acids, halogens, salts of Ag[f]	Inh, abs, ing con[f]	Eyes, skin, resp sys[f]	Not Classified
Antimony (Nonradionuclide)	7440-36-0	Insoluble[d]	0 mm (approx)[d]	Noncombustible as solid bulk; moderate explosion hazard as dust exposed to flame[d]	Strong oxidizers, acids, halogenated acids[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CVS[d]	EPA Group D[e]
Arsenic (Insol cmpds/metal)	7440-38-2	Insoluble[d]	0 mm (approx)[d]	Metal: Noncombustible as solid bulk; slight explosion hazard as dust exposed to flame[d]	Strong oxidizers, bromine azide[d]	Inh, abs, con, ing[d]	Liver, kidneys, skin, lungs, lymphatic sys (lung and lymphatic cancer)[d]	EPA Group A[e]
Barium	7440-39-3	None Found	10 mm (1049 °C)[f]	Flammable solid spontaneously combustible; dangerous when wet[f]	Water, acids, carbon tetrachloride, fluorotrichloromethane, trichloroethylene, and tetrachloroethylene[f]	None Found	None Found	Not Classified
Benzene	71-43-2	0.07%[d]	75 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, many fluorides and perchlorates, nitric acid[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, blood, CNS, bone marrow (leukemia)[d]	EPA Group A[e]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Beryllium (metal)	7440-41-7	Insoluble[d]	0 mm[d]	Metal: Noncombustible as solid bulk; slight explosion as dust[d]	Acids, caustics, chlorinated hydrocarbons, oxidizers, molten Li[d]	Inh, con[d]	Eyes, skin, resp sys, (lung cancer)[d]	EPA Group B[e]
Bismuth	7440-69-9	Insoluble[g]	1 mm (1021 °C)[f]	Flammable when exposed to flame[f]	Incompatible with Al, BrF_3, acids, NOF, ammonium nitrate, perchloric acid, chloride, IF_5, nitric acid[f]	None Found	None Found	Not Classified
Boric acid	10043-35-3	1g in 18 ml cold water[g]	Volatile with steam[g]	None Found	K, acetic anhydride[f]	Inh, abs, inq, con[f]	Eyes, skin, resp sys, GI[f]	Not Classified
1,3-Butadiene	106-99-0	Insoluble[d]	2.4 atm[d]	Class I Flammable liquid[d]	Phenol, chlorine dioxide, Cu, crotonaldehyde[d]	Inh, con (liq)[d]	Eyes, skin, resp sys, CNS, repro sys (Hemato cancer)[d]	EPA Group B2[e]
n-Butane	106-97-8	Slightly soluble[d]	2.05 atm[d]	Class IA Flammable liquid[d]	Strong oxidizers, chlorine, fluorine, (Ni carbonyl+O_2)[d]	Inh, con (liq)[d]	CNS[d]	Not Classified
1-Butene (butylene)	106-98-9	None Found	3,480 mm[f]	Flammable gas[f]	Aluminium hydroborate[f]	Simple asphyxiant[f]	None Found	Not Classified
2-Butoxyethanol	111-76-2	Miscible[d]	0.8 mm[d]	Class IIIA Combustible liquid[d]	Strong oxidizers, strong caustics[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, blood, kidneys, liver, lymphoid sys[d]	Not Classified
n-Butyl alcohol (1-butanol)	71-36-3	9%[d]	6 mm[d]	Class IC Flammable liquid[d]	Strong oxidizers, strong mineral acids, alkali metals, halogens[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, CNS[d]	EPA Group D[e]
Butyl lactate	138-22-7	Slightly soluble[d]	0.4 mm[d]	Class IIIA Combustible liquid[d]	Strong acids, bases, oxidizers, heat, sparks, open flames[d]	Inh, ing, con[d]	Eyes, skin, resp. sys, CNS[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Cadmium dust (Nonradionuclide)	7440-43-9	Insoluble[d]	0 mm (approx)[d]	Noncombustible as solid bulk; will burn as powder[d]	Strong oxidizers, elemental S, Se, and Te[d]	Inh, ing[d]	Resp sys, kidneys, prostate, blood (prostatic and lung cancer)[d]	EPA Group B1[e]
Cadmium oxide (fume)	1306-19-0	Insoluble[d]	0 mm (approx)[d]	Noncombustible solid[d]	Not applicable[d]	Inh[d]	Resp sys, kidneys, prostate, blood (prostatic and lung cancer)[d]	Not Classified
Calcium	7440-70-2	Reacts with water[g]	10 mm (983 °C)[h]	Flammable solid, Spontaneously combustible[f]	Strong oxidizing agents, acids, water, alkali metal hydroxides or carbonates, halogens, Ph, Si, Hg[f]	None Found	None Found	Not Classified
Carbon dioxide	124-38-9	Sublimes[d]	56.5 atm[d]	Non-flammable gas[d]	Dusts of metals (eg. Mg, Zr, Ti, Al, Cr, and Mn) are ignitable and explosive when suspended in CO_2[d]	Inh, con (liq/soln)[d]	Resp sys, CVS[d]	Not Classified
Carbon disulfide	75-15-0	0.3%[d]	297 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers; chemically-active metals (eg. Na, K, and Zn); azides; rust; halogens; amines[d]	Inh, abs, ing, con[d]	CNS, PNS, CVS, eyes, kidneys, liver, skin, repro sys[d]	Not Classified
Carbon monoxide	630-08-0	2%[d]	>35 atm[d]	Flammable gas[d]	Strong oxidizers, bromine trifluoride, chlorine trifluoride, Li[d]	Inh, con (liq)[d]	CVS, lungs, blood, CNS[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Carbon tetrachloride	56-23-5	0.05%[d]	91 mm[d]	Non-combustible liquid[d]	Chemically-active metals (eg. Na, K, and Mg), F_2, Al[d]	Inh, abs, ing, con[d]	CNS, eyes, lungs, liver, kidneys, skin (In animals: liver cancer)[d]	EPA Group B2[e]
Chloride (Sodium chloride)	77647-14-5	Soluble[f]	1 mm (865 °C)[f]	Decomposes[f]	Potentially explosive reaction with dichloromaleic anhydride+urea; Violent reaction with BrF_3[f]	Inh, abs, ing, con, ipr, sca[f]	Eyes, skin, GI tract, repro sys, resp sys[f]	Not Classified
Chlorine	7782-50-5	0.7%[d]	6.8 atm[d]	Non-flammable gas[d]	Reacts explosively or forms explosive cmpds with many common substances (e.g., acetylene, ether, turpentine, ammonia, fuel gas, hydrogen and finely divided metals)[d]	Inh, con[d]	Eyes, skin, resp sys[d]	EPA Group D[e]
Chlorobenzene	108-90-7	0.05%[d]	9 mm[d]	Class IC Flammable liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, liver[d]	Not Classified
Chloroform	67-66-3	0.5% (77 °F)[d]	160 mm[d]	Non-combustible liquid[d]	Strong caustics, chemically active metals (e.g., Al or Mg powder, Na, and K), strong oxidizers[d]	Inh, abs, ing, con[d]	Liver, kidneys, heart, skin, CNS (In animals: liver and kidney cancer)[d]	EPA Group B2[e]
bis-Chloromethyl ether	542-88-1	Reacts in water (68 °F)[d]	30 mm (72 °F)[d]	Class IB Flammable liquid[d]	Acids, water[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys[d]	EPA Group A[e]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Chromium (Hexavalent); Chromium[VI] oxide	18540-29-9; 1333-82-0 (CrO_3; acid)	None Found	Decomp, 61.7 g/100cc (0 °C)[f]	Corrosive crystal[f]	N,N-Dimethylformamide, explosive reaction or ignites with organic materials and solvents, alcohols and alkali metals (e.g., acetaldehyde, benzene, ethyl acetate, and heat + acetic acid or acetic anhydride, acetone, methanol, butanol, Na, and K)[f]	Inh, abs, ing, con, ipr[f]	Eyes, skin, resp sys, repro sys (Human cancer of nasal cavity and lungs)[f]	EPA Group A[e]
Chromium (Trivalent)	16065-83-1	Varies with cmpd[d]	Varies with cmpd[d]	Varies with cmpd[d]	Varies with cmpd[d]	Inh, ing, con[d]	Eyes, skin[d]	Not Classified
Cobalt (Metal dust and fume)	7440-48-4	Insoluble[d]	0 mm (approx)[d]	Noncombustible solid in bulk form; fine dust burns at high temp[d]	Strong oxidizers, ammonium nitrate[d]	Inh, ing, con[d]	Skin, resp sys[d]	Not Classified
Copper (Dusts and mists)	7440-50-8	Insoluble[d]	0 mm (approx)[d]	Noncombustible solid in bulk; powder may ignite[d]	Oxidizers, alkalis, sodium azide, acetylene[d]	Inh, ing, con[d]	Eyes, skin, resp sys, liver, kidneys (Increase risk with Wilson's disease)[d]	EPA Group D[e]
Cresol (*m*-cresol, cresylic acid)	108-39-4	2%[d]	0.14 mm (77 °F)[d]	Class IIIA Combustible liquid[d]	Strong oxidizers, acids[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys, CNS, pancreas, CVS[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Cyclohexane	110-82-7	Insoluble[d]	78 mm[d]	Class IB Flammable liquid[d]	Oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Cyclohexanone	108-94-1	15%[d]	5 mm[d]	Class IIIA Combustible liquid[d]	Oxidizers, nitric acid[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, CNS, liver, kidneys[d]	Not Classified
Cyclopentane	287-92-3	Insoluble[d]	400 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers (e.g., chlorine, bromine, fluorine)[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Diacetone alcohol	123-42-2	Miscible[d]	1 mm[d]	Class II Combustible liquid[d]	Strong oxidizers, strong alkalis[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, liver[d]	Not Classified
Dibenzofuran	132-64-9	None Found	None Found	None Found	None Found	None Found	None Found	None Found
Dibutyl phosphate	107-66-4	Insoluble[d]	1 mm (approx)[d]	Class IIIB Combustible liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	Not Classified
o-Dichlorobenzene	95-50-1	0.01%[d]	1 mm[d]	Class IIIA Combustible liquid[d]	Strong oxidizers, Al, chlorides, acids, acid fumes[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys[d]	Not Classified
3,3-Dichlorobenzidine	91-94-1	7% (59 °F)[d]	None Found	None Found	None Found	Inh, abs, ing, con[d]	Bladder, liver, lung, GI tract (In animals: liver and bladder cancer)	EPA Group B2[e]
Dichlorodifluoromethane	75-71-8	0.03% (77 °F)[d]	5.7 atm[d]	Nonflammable gas[d]	Chemically active metals (e.g., Na, K, Ca, powdered Al, Zn, and Mg)[d]	Inh, con (liq)[d]	CVS, PNS	EPA Group D[e]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Dichloromethane (Methylene chloride)	75-09-2	2%[d]	350 mm[d]	Combustible liquid[d]	Strong oxidizers, caustics, chemically active metals (eg., Al, Mg powders, K and Na), conc nitric acid[d]	Inh, abs, ing, con[d]	Eyes, skin, CVS, CNS, (In animals: lung, liver, salivary and mammary gland tumors)[d]	EPA Group B2[e]
Dimethylformamide (DMF)	68-12-2	Miscible[d]	3 mm[d]	Class II Combustible liquid[d]	Carbon tetra chloride, other halogenated cmpds when in contact with iron; strong oxidizers, alkyl aluminums, inorganic nitrates[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys, CVS[d]	Not Classified
2,4-Dinitrotoluene	25321-14-6	Insoluble[d]	1 mm[d]	Combustible solid, but difficult to ignite[d]	Strong oxidizers, caustics, metals such as tin and zinc[d]	Inh, abs, ing, con[d]	Blood, liver, CVS, repro sys (In animals: liver, skin, and kidney tumors)[d]	Not Classified
1,4-Dioxane	123-91-1	Miscible[d]	29 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, decaborane, triethynyl aluminum	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys (In animals: lung, liver and nasal cavity tumors)[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Di-sec octyl phthalate	117-81-7	0.00003% (75 °F)[d]	<0.01 mm[d]	Class IIIB Combustible liquid[d]	Nitrates, strong oxidizers, acids and alkalis[d]	Inh, ing, con[d]	Eyes, resp sys, CNS, liver, repro sys, GI tract (In animals: liver tumors)[d]	Not Classified
Dodecane	112-40-3	None Found	None Found	None Found	None Found	None Found	None Found	Not Classified
Ethane	74-84-0	Soluble (20 °C)[d]	None Found	Flammable asphyxiant[f]	None Found	Simple asphyxiant[f]	None Found	Not Classified
Ethanol (ethyl alcohol)	64-17-5	Miscible[d]	44 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, potassium dioxide, bromine pentafluoride, acetyl bromide, acetyl chloride, Pt, Na[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, liver, blood, repro sys[d]	Not Classified
Ethyl acetate	141-78-6	10% (77 °F)[d]	73 mm[d]	Class IB Flammable liquid[d]	Nitrates, strong oxidizers, alkalis and acids[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	Not Classified
Ethyl benzene	100-41-4	0.01%[d]	7 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	EPA Group D[e]
Ethylene	74-85-1	20% (0 °C)[g]	None Found	Flammable[g]	None Found	Simple asphyxiant[f]	None Found	Not Classified
Ethylene dichloride	107-06-2	0.9%[d]	64 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers & caustics; chemically-active metals (e.g., Mg or Al powder), Na and K; liquid ammonia[d]	Inh, abs, ing, con[d]	Eyes, skin, kidneys, liver, CNS, CVS (In animals: fore-stomach, mammary gland & circulatory sys cancer)[d]	Not Classified
Ethyl ether	60-29-7	8%[d]	440 mm[d]	Class IA Flammable liquid[d]	Strong oxidizers, halogens, sulfur, sulfur cmpds[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Ethylene glycol	107-21-1	Miscible[d]	0.06 mm[d]	Class III B Combustible liquid[d]	Strong oxidizers, chromium trioxide, potassium permanganate, sodium peroxide (hygroscopic)[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	EPA Group D[e]
Ethylene glycol monoethyl ether (2-ethoxyethanol, Cellosolve®)	110-80-5	Miscible[d]	4 mm[d]	Class II Combustible liquid[a]	Strong oxidizers[d]	Inh, abs, ing, con[d]	Eyes, resp, kidneys, liver, repro sys, hemato sys[d]	Not Classified
Ethyltriacetyoxysilane	None Found	None Found	None Found	None Found	None Found	None Found	None Found	Not Classified
Fluoride	None Found	Varies with cmpd[d]	Varies with cmpd[d]	Varies with cmpd[d]	Varies with cmpd[d]	None Found	None Found	Not Classified
Formaldehyde	50-00-0	Miscible[d]	>1 atm[d]	Flammable gas[d]	Strong oxidizers, alkalis; acids; phenols, urea, (Tends to polymerize; Reacts with HCl to form bis-chloromethyl ether)[d]	Inh, con[a]	Eyes, resp sys, (nasal cancer)[d]	EPA Group B1[e]
Formic acid	64-18-6	Miscible[d]	35 mm[d]	Class II Combustible liquid[d]	Strong oxidizers, strong caustics, concentrated sulfuric acid[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	Not Classified
n-Heptane	142-82-5	0.0003%[d]	40 mm (72 °F)[d]	Class 1B Flammable liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Skin, resp sys, CNS[d]	EPA Group D
n-Hexane	110-54-3	0.002%[d]	124 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Skin, eyes, CNS, PNS, resp sys[d]	EPA Group D[i]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Hydrazine	302-01-2	Miscible[d]	10 mm[d]	Class IC Flammable liquid[d]	Oxidizers, hydrogen peroxide, nitric acid, metallic oxides, acids (Can ignite spontaneously on contact with oxidizers or porous materials such as earth, wood and cloth)[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, CNS, liver, kidneys (In animals: tumors of lung, liver, blood vessels and intestines)[d]	EPA Group B2[e]
Hydrogen chloride (hydrochloric acid)	7647-01-0	67% (86 °F)[d]	40.5 atm[d]	Non-flammable gas[d]	Hydroxides, amines, alkalis, Cu, brass, Zn (Highly corrosive to metals)[d]	Inh, ing (soln), con[d]	Resp sys, skin, eyes[d]	Not Classified
Hydrogen cyanide	74-90-8	Miscible[d]	630 mm[d]	Class IA Flammable gas[d]	Amines, oxidizers, acids, sodium hydroxide, calcium hydroxide, sodium carbonate, water, caustics, ammonia (Can polymerize at 122-140 °F)[d]	Inh, abs, ing, con[d]	CNS, CVS, thyroid, blood[d]	Not Classified
Hydrogen fluoride (hydrofluoric acid)	7664-39-3	Miscible[d]	783 mm[d]	Non-flammable gas[d]	Metals, water or steam (Corrosive to metals. Will attack glass and concrete)[d]	Inh, abs(liq), ing (soln), con[d]	Eyes, skin, resp sys, bones[d]	Not Classified
Hydrogen peroxide	7722-84-1	Miscible[d]	5 mm (86 °F)[d]	Noncombustible liquid, but a powerful oxidizer[d]	Oxidizable materials, Fe, Cu, brass, bronze, Cr, Zn, Pb, Ag, Mn[d]	Inh, ing, con[d]		Not Classified
Hydrogen sulfide	7783-06-4	0.4%[d]	17.6 atm[d]	Flammable gas[d]	Strong oxidizers, strong nitric acid, metals[d]	Inh, con[d]	Resp sys, CNS, eyes[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Iron salts (Soluble as Fe)	None	Varies with cmpd[d]	Varies with cmpd[d]	Non-combustible solids[d]	Varies with cmpd[d]	Ing, ing, con[d]	Eyes, skin, liver, resp sys, GI tract[d]	Not Classified
Isobutane	75-28-5	Slight[d]	3.1 atm (70 °F)[d]	Class IA Flammable gas[d]	Strong oxidizers (e.g., nitrates and perchlorates), chlorine, fluorine (Ni carbonyl + O_2)[d]	Inh, con (liq)[d]	CNS[d]	Not Classified
Isobutanol (Isobutyl alcohol)	78-83-1	10%[d]	9 mm[d]	Flammable[g]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Isobutyl acetate	110-19-0	0.6% (77 °F)[d]	13 mm[d]	Class 1B Flammable liquid	Nitrates, strong oxidizers, alkalis, acids[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Isopropyl alcohol	67-63-0	Miscible[d]	33 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, acetaldehyde, chlorine, ethylene oxide, acids, isocyanates	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Kerosene	8008-20-6	Insoluble[d]	5 mm (100 °F)[d]	Class II Combustible liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	IARC Group 2A (suspect carcinogen)
Lead	7439-92-1	Insoluble[d]	0 mm (approx)[d]	Non-combustible solid in bulk form[d]	Strong oxidizers, hydrogen peroxide, acids[d]	Inh, ing, con[d]	Eyes, GI tract, CNS, kidneys, blood, gingival tissue[d]	EPA Group B2[e]
Lead chromate	7758-97-6[f]	0.000007 (20 °C)[h]	Not Applicable	None Found	Potentially explosive reactions with azo-dye stuffs; Violent reaction with Al + dinitro-naphthalene + heat[f]	Con, ing, scu, ipr[f]	GI tract[f]	Confirmed carcinogen
Lithium	7439-93-2	None Found	None Found	None Found	None Found	None Found	Kidneys[g]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Lithium hydride	7580-67-8	Reacts with water[d]	0 mm (approx)[d]	Combustible solid that can form airborne dust clouds which may explode on contact with flame heat, or oxidizers[d]	Strong oxidizers, halogenated hydrocarbons, acids, water (May ignite spontaneously in air)[d]	Inh, ing, con[d]	Skin, eyes, resp sys, CNS[d]	Not Classified
Magnesium (oxide fume)	1309-48-4	0.009% (86 °F)[d]	0 mm (approx)[d]	Non-combustible solid[d]	Chlorine trifluoride, phosphorus pentachloride[d]	Inh, con[d]	Eyes, resp sys[d]	Not Classified
Manganese (cmpds as fume; as Mn)	7439-96-5	Insoluble[d]	0 mm (approx)[d]	Metal: Combustible solid[d]	Oxidizers (Will react with water to produce H_2)[d]	Inh, ing[d]	Resp sys, blood, CNS, kidneys[d]	EPA Group D[e]
Mercury (Cmpds except organo alkyls; as Hg)	7439-97-6	Insoluble[d]	0.0012 mm[d]	Metal: Non-combustible liquid[d]	Acetylene, ammonia, chlorine dioxide, azides, calcium, sodium carbide, Li, Rb, Cu[d]	Inh, abs, inh, con[d]	Eyes, skin, resp sys, CNS, kidneys[d]	EPA Group D[e]
Methanol (methyl alcohol)	67-56-1	Miscible[d]	96 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, CNS, GI tract[d]	Not Classified
Methyl chloride	74-87-3	0.5%[d]	5.0 atm[d]	Flammable gas[d]	Chemically-active metals (e.g., Al, Zn, and Mg), water[d]	Inh, con (liq)[d]	CNS, liver, kidneys, repro sys[d]	Not Classified
Methylene chloride (dichloromethane)	75-09-2	2%[d]	350 mm[d]	Combustible liquid[d]	Strong oxidizers; caustics; chemically active metals (e.g. Al, Mg powders, K and Na), conc nitric acid[d]	Inh, abs, ing, con[d]	Skin, CVS, eyes, CNS (In animals: lung, liver, salivary gland, and mammary gland tumors)[d]	EPA Group B2[e]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Methyl ethyl ketone (MEK; 2-butanone)	78-93-3	28%[d]	78 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, amines, ammonia, inorganic acids, caustics, Cu, isocyanates, pyridines[d]	Inh, ing, con[d]	CNS, resp sys, skin, eyes[d]	EPA Group D[e]
Methyl isobutyl ketone (MIBK; Hexone)	108-10-1	2%[d]	16 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, potassium tert-butoxide[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, liver, kidneys[d]	Not Classified
Naphthalene (naphthene)	91-20-3	0.003%[d]	0.08 mm[d]	Combustible solid, but will take some effort to ignite[d]	Strong oxidizers, chromic anhydride[d]	Inh, abs, ing, con[d]	Eyes, skin, blood, liver, kidneys, CNS[d]	EPA Group D[e]
Nickel (refinery dust)	7440-02-0	Insoluble[d]	0 mm (approx)[d]	Metal: Combustible solid; Ni sponge catalyst ignites spontaneously in air[d]	Strong acids, S, Se, wood and other combustibles, nickel nitrate[d]	Inh, ing, con[d]	Lungs, skin, nasal cavities (lung and nasal cancer)[d]	EPA Group A[e]
Nitric acid	7697-37-2	Miscible[d]	48 mm[d]	Noncombustible liquid, but increases flammability of combustible materials	Combustible materials; metallic powders; hydrogen sulfide; carbides; alcohols (Corrosive to metals)[d]	Inh, ing, con[d]	Eyes, resp sys, skin, teeth[d]	Not Classified
Nitrobenzene	98-95-3	0.2%[d]	0.3 mm (77 °F)[d]	Class IIIA Combustible liquid[d]	Conc. nitric acid, nitrogen tetroxide, caustics, phosphorous pentachloride, chemically-active metals (e.g., Sn, Zn)[d]	Inh, abs, ing, con[d]	Eyes, skin, blood, liver, kidneys, CVS, repro sys[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
2-Nitropropane	74-46-9	2%[d]	13 mm[d]	Class IC Flammable liquid[d]	Amines; strong acids, alkalis & oxidizers; metal oxides; combustible materials[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, liver, kidneys (In animals: liver tumors)[d]	EPA Group B2[d]
Octanol	None Found	None Found	None Found	None Found	None Found	None Found	None Found	Not Classified
Oxalic acid	144-62-7	14%[d]	<0.001 mm[d]	Combustible solid[d]	Strong oxidizers, silver cmpds, strong alkalis, chlorites[d]	Inh, ing, con[d]	Eyes, skin, resp sys, kidneys[d]	Not Classified
Ozone	10028-15-6	0.001% (32 °F)[d]	>1 atm[d]	Nonflammable gas, but a powerful oxidizer[d]	All oxidizable materials (inorganic and organic)[d]	Inh, con[d]	Eyes, resp sys[d]	Not Classified
Phenol	108-95-2	9% (77 °F)[d]	0.4 mm	Sp. Gr: 1.06 Combustible solid	Strong oxidizer, calcium hypochlorite, aluminum, chloride, acids)	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys	EPA Group D[e]
Phosphoric acid	7664-38-2	Miscible[d]	0.03 mm[d]	Noncombustible liquid[d]	Strong caustics, most metals (Do not mix with solutions containing bleach or ammonia)[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	Not Classified
Phosphorous (yellow)	7723-14-0	0.0003%[d]	0.03 mm[d]	Flammable solid[d]	Air, oxidizers (Including elemental S and strong caustics), halogens (Ignites spontaneously in moist air)[d]	Inh, ing, con[d]	Eyes, skin, resp sys, liver, kidneys, jaw, teeth, blood[d]	Not Classified
Phosgene	75-44-5	Slight[d]	1.6 atm[d]	Non-flammable gas[d]	Moisture, alkalis, ammonia, alcohols, Cu[d]	Inh, con (liq)[d]	Eyes, skin, resp sys[d]	Not Classified
Plutonium oxide	None Found	None Found	None Found	None Found	None Found	None Found	None Found	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Potassium chromate (VI)	7789-00-6	Soluble in 1.6 parts cold water[g]	None Found	None Found	None Found	None Found	None Found	Confirmed carcinogen[f]
Potassium hydroxide	1310-58-10	107% (59 °F)[d]	1 mm (1317 °F)[d]	Noncombustible solid, may react with H_20 and other substances and generate sufficient heat to ignite combustible materials[d]	Acids, water, metals (When wet), halogenated hydrocarbons, maleic anhydride[d]	Inh, ing, con[d]	Eyes, skin, resp sys[a] (throat, esophagus, mucous membranes)[f]	Not Classified
Propane	74-98-6	0.01%[d]	8.4 atm (70 °F)[d]	Flammable gas[d]	Strong oxidizers[d]	Inh, con (liq)[d]	CNS[d]	Not Classified
Propene (propylene)	115-07-1	None Found	7-8 atm[g]	Flammable gas[g]	None Found	Simple ashyxiant[g]	None Found	Not Classified
Propionaldehyde	123-38-6	Miscible[f]	None Found	Flammable liquid[f]	Oxidizers, vigorous polymerization reaction with methyl methacrylate[f]	Inh, ing, abs, con[f]	Skin, GI tract, resp sys[f]	Not Classified
Propylene oxide	75-56-9	41%[d]	445 mm[d]	Class 1A Flammable liquid[d]	Anhydrous metal chlorides; Fe; strong acids, caustics and peroxides[d]	Inh, ing, con[d]	Eyes, skin, resp sys[d]	EPA Group B2[e]
Pyridine	110-86-1	Miscible[d]	16 mm[d]	Class IB combustible liquid[d]	Strong oxidizers, strong acids[d]	Inh, ing, abs, con[d]	Eyes, skin, CNS, liver, kidneys, GI tract[d]	Not Classified
Pyrene	129-00-0	Insoluble[g]	None Found	None Found	None Found	None Found	None Found	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Selenium	7782-49-2	Insoluble[d]	0 mm (approx)[d]	Combustible solid[d]	Acids, strong oxidizers, chromium trioxide, potassium bromate, Cd[d]	Inh, ing, con[d]	Eyes, skin, resp sys, liver, kidneys, blood, spleen[d]	EPA Group D[e]
Silicon	7440-21-3	Insoluble[d]	0 mm (approx)[d]	Combustible solid in powder form[d]	Chlorine, fluorine, oxidizers, calcium, cesium carbide, alkaline carbonates[d]	Inh, ing, con[d]	Skin, eyes, resp sys[d]	Not Classified
Silver	7440-22-4	Insoluble[d]	0 mm (approx)[d]	Metal: Non-combustible solid, but flammable as dust or powder[d]	Acetylene, ammonia, hydrogen peroxide, bromoazide, chlorine, trifluoride, ethyleneimine, oxalic acid, tartaric acid[d]	Inh, ing, con[d]	Nasal septum, skin, eyes[d]	EPA Group D[e]
Stoddard Solvent	8052-41-3	Insoluble	None Found	Class II Combustible liquid[d]	Strong oxidizers[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, kidneys[d]	Not Classified
Styrene	100-42-5	0.03%[d]	5 mm[d]	Class IC Flammable liquid[d]	Oxidizers, catalysts for vinyl polymers, peroxides, strong acids, aluminum chloride (May polymerize if contaminated or subjected to heat)[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, CNS, liver, repro sys[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Sulfuric acid	7664-93-9	Miscible[d]	0.001 mm[d]	Noncombustible liquid, but capable of igniting finely divided combustible materials[d]	Organic materials, chlorates, carbides, fulminates, water, powdered metals[d]	Inh, ing, con[d]	Resp sys, eyes, skin, teeth[d]	Not Classified
Tetrachloroethylene	127-18-4	0.02%[d]	14 mm[d]	Noncombustible liquid, but decomposes in a fire to HCl and phosgene[d]	Strong oxidizers, chemically-active metals (e.g., Li, Be & Ba), caustic soda, sodium hydroxide, potash[d]	Inh, abs, ing, con[d]	Eyes, skin, resp sys, liver, kidneys, CNS (In animals: liver tumors)[d]	Not Classified
Tetrahydrofuran (THF)	109-99-91	Miscible[d]	132 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers, Li-Al alloys[d]	Inh, ing, con[d]	Eyes, resp sys, CNS[d]	Not Classified
Titanium	7440-32-6	None Found	None Found	None Found	None Found	None Found	None Found	Not Classified
Toluene	108-88-3	0.07% (74 °F)[d]	21 mm[d]	Class IB Flammable liquid[d]	Strong oxidizers[d]	Inh, abs, ing, con[d]	CNS, eyes, resp sys, liver, kidneys, skin[d]	EPA Group D[e]
Tributyl phosphate	126-73-8	0.6%[d]	0.004 mm (77 °F)[d]	Class III B[d]	Alkalis, oxidizers, water, moist air	Inh, ing, con[d]	Eyes, skin, resp. sys.	Not Classified
1,1,1-Trichloroethane (TCA; methyl chloroform)	71-55-6	0.4%[d]	100 mm[d]	Combustible liquid, but burns with difficulty[d]	Strong caustics; strong oxidizers; chemically-active metals (e.g., Zn, Al, Mg powders, Na, and K); water[d]	Inh, ing, con[d]	CNS, eyes, skin, liver, CVS[d]	EPA Group D[e]

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
1,1,2-Trichloroethane	79-00-5	0.4%[d]	19 mm[d]	Combustible liquid, forms dense soot[d]	Strong oxidizers & caustics; chemically-active metals (e.g., Al, Mg powders, Na, and K)[d]	Inh, abs, ing, con[d]	Eyes, resp sys, CNS, liver, kidneys (In animals: liver cancer)[d]	Not Classified
Trichloroethylene (TCE, trichloroethene)	79-01-6	0.0001% (77 °F)[d]	58 mm[d]	Combustible liquid, but burns with difficulty[d]	Strong caustics & alkalis; chemically-active metals (e.g., Ba, Li, Na, Mg, Ti, and Be)[d]	Inh, abs, ing, con[d]	Eyes, resp sys, heart, liver, CNS, skin (In animals: liver and kidney cancer)[d]	EPA Group B2[i]
Trichlorotrifluoroethane (Freon 113)	76-13-1	0.02% (77 °F)[d]	285 mm[d]	Noncombustible liquid at ordinary temp, but will ignite and burn weakly at 1256 °F[d]	Chemically-active metals (e.g., Ca, powdered Al, Zn, Mg and Be)[d]	Inh, ing, con[d]	Skin, heart, CNS, CVS[d]	Not Classified
1,2,4-Trimethylbenzene	95-63-6	0.006%[d]	1 mm (56 °F)[d]	Class II Flammable liquid[d]	Oxidizers, nitric acid[d]	Inh, ing, con[d]	Eyes, skin, resp sys, CNS, blood[d]	Not Classified
Tungsten (insoluble compounds)	7440-33-7	Insoluble[d]	0 mm (approx)[d]	Combustible as fine powder; may ignite spontaneously[d]	Bromine trifluoride, chlorine trifluoride, F_2, I_2, pentafluoride[d]	Inh, ing, con[d]	Eyes, skin, resp sys, blood[d]	Not Classified
VM&P Naphtha	8032-32-4	Insoluble	2-20 mm	Class IB Flammable liquid[d]	None Found	Inh, ing, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified

Table M.3.2–1. Chemical Toxicity Profiles—Continued

Compound	CAS No.	Solubility	Vapor Pressure	Flammability[a]	Incompatibilities	Route of Exposure[b]	Target Organs	Carcinogenicity[c]
Welding fumes	ZC2550000	Varies with component of fumes[d]	Varies with component of fumes[d]	Varies with component of fumes[d]	Varies with component of fumes[d]	Inh, con[d]	Eyes, skin, resp sys, CNS[d]	Not Classified
Xylene (o-, m-, p- mixture)	o: 95-47-6 m:108-38-3 p: 106-42-3	o: 0.02%[d] m: slight[d] p: 0.02%[d]	o: 7 mm[d] m 9 mm[d] p: 9 mm[d]	o-, m-, p-: Class IC Flammable liquids[d]	o-, m-, p-: Strong oxidizers, strong acids[d]	o-, m-, p-: inh, abs, ing, con[d]	o-, m-, p-: Eyes, skin, resp sys, CNS, GI tract, liver, blood, kidneys[d]	Not Classified
Zinc	7440-66-6	None Found	None Found	Combustible solid[g]	None Found	Inh[g]	None Found	Not Classified

[a] Flammable liquids are classified by OSHA (29 CFR 1910.106) as follows:
Class IA...flash point below 73 °F and boiling point below 100 °F.
Class IB...flash point below 73 °F and boiling point at or above 100 °F.
Class IC...flash point at or above 73 °F and below 140 °F.
Class II... flash point at or above 100 °F and below 140 °F.
Class IIIA... flash point at or above 140 °F and below 200 °F.
Class IIIB...flash point at or above 200 °F.
DHHS 1992a.

[b] Routes of exposure abbreviated as follows:
inh-inhalation
abs-skin absorption
ing-ingestion
con-skin and/or eye contact
ipr-intraperitoneal
scu-subcutaneous.

[c] EPA Groups for carcinogenicity are classified as follows:
EPA Group A: Human Carcinogen
EPA Group B1: Probable Human Carcinogen-limited evidence in human studies
EPA Group B2: Probable Human Carcinogen-sufficient evidence from animal studies, inadequate evidence or no data from human studies
EPA Group C: Possible Human Carcinogen
EPA Group D: Not Classifiable as to Human Carcinogenicity.

[d] NIOSH 1994a.

[e] ORNL 1994b.

[f] Lewis 1992a.

[g] Merck 1989a.

[h] Lange 1967a.

[i] EPA 1993a.

M.3.3 REGULATED EXPOSURE LIMITS

Hazardous chemicals are regulated by various agencies in order to provide protection to the public (EPA regulated) and to workers OSHA, while others (National Institute for Occupational Safety and Health [NIOSH] and the ACGIH) provide guidelines. The RfDs and RfCs set by EPA represent exposure limits for long-term (chronic) exposure at low doses and concentrations, respectively, that can be considered safe from non-cancerous effects. The PEL represents concentration levels set by OSHA that are safe for 8-hr exposures without causing non-cancerous effects. The slope factor, or the unit risk, is used to convert the daily uptake of a carcinogenic chemical averaged over a lifetime to the incremental risk of an individual developing cancer. Table M.3.3–1 presents the information on exposure limits used to develop HQs for each of the hazardous chemicals and the HIs derived from their summation and the slope factors used to calculate cancer risk for each chemical at the exposure concentrations identified at the various sites or associated with a proposed alternative action.

Table M.3.3–1. Table of Exposure Limits

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Acetaldehyde	75-07-0	0.003[d]	$9x10^{-3}$[e]	EPA Group B2[e]	none found	OSHA-PEL: 360 mg/m^3 ACGIH-TLV: 180 mg/m^3, STEL: 270 mg/m^3 NIOSH-REL: 3,660 mg/m^3
Acetic acid	64-19-7	0.175[f]	0.6125[g]	not classified	none found	OSHA-PEL: 25 mg/m^3 ACGIH-TLV: 25 mg/m^3, STEL: 37 mg/m^3 NIOSH-REL: 25 mg/m^3, STEL: 37 mg/m^3 IDLH: 125 mg/m^3
Acetone	67-64-1	0.1[e]	0.35[g]	EPA Group D[e]	none found	OSHA-PEL: 2,400 mg/m^3 ACGIH-TLV: 1,780 mg/m^3 NIOSH-REL: 590 mg/m^3 STEL: 2,380 mg/m^3 IDLH: 6,050 mg/m^3
Acetonitrile	75-05-8	0.006[e]	0.021[g]	not classified	none found	OSHA-PEL: 70 mg/m^3 ACGIH-TLV: 67 mg/m^3 STEL: 101 mg/m^3 NIOSH-REL: 34 mg/m^3 IDLH: 855 mg/m^3
Acetylene	74-86-2	18.634[h]	65.219[g]	not classified	none found	OSHA-PEL: 2,662 mg/m^3[i] NIOSH-REL: 2,662 mg/m^3
Aluminum	7429-90-5	0.105[f]	0.368[g]	not classified	none found	OSHA-PEL: 15 mg/m^3 ACGIH-TLV: 10 mg/m^3, (dust) NIOSH-REL: 10 mg/m^3
Aluminum welding fumes	none	0.035[h]	0.1225[g]	not classified	none found	NIOSH-REL: 5 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Ammonia	7664-41-7	$2.86x10^{-2}$[d], (34 mg/L, chronic)[j]	0.1[e]	EPA Group D[k]	none found	OSHA-PEL: 35 mg/m^3 ACGIH-TLV: 17 mg/m^3, STEL: 24 mg/m^3 NIOSH-REL: 18 mg/m^3, STEL: 27 mg/m^3 IDLH: 213 mg/m^3
Ammonium hydroxide	1336-21-6	0.014[l]	0.049[g]	not classified	none found	LD50 (oral-rat): 350 mg/kg[i] PEL: 2 mg/m^3[m]
Antimony (nonradionuclide)	7440-36-0	$4x10^{-4}$[e]	$1.4x10^{-3}$[g]	EPA Group D[k]	none found	OSHA-PEL: 0.5 mg/m^3 ACGIH-TLV: 0.5 mg/m^3 NIOSH-REL: 0.5 mg/m^3, IDLH: 50 mg/m^3, IDLH: 50 mg/m^3
Arsenic	7440-38-2	$3x10^{-4}$[e]	$1.05x10^{-3}$[g]	EPA Group A[e]	50 (inhal)[j]	OSHA-PEL: 0.01 mg/m^3[i] ACGIH-TLV: 0.2 mg/m^3 NIOSH-REL: 0.002 mg/m^3 (ceiling), IDLH: 5 mg/m^3
Barium	7440-39-3	0.07[n]	0.245[g]	not classified	none found	OSHA-PEL: 0.5 mg/m^3[i] ACGIH-TLV: 0.5 mg/m^3 (sol. cmpds. as Ba)
Benzene	71-43-2	$2.28x10^{-2}$[f]	0.0798[g]	EPA Group A	0.029 (oral)[e] 0.029 (inhal)[j]	OSHA-PEL: 3.25 mg/m^3, STEL: 16.25 mg/m^3 ACGIH-TLV: 32 mg/m^3 NIOSH-REL: 0.325 mg/m^3, STEL: 3.25 mg/m^3, IDLH: 5 mg/m^3
Beryllium	7440-41-7	$5x10^{-3}$[e]	0.0175[g]	EPA Group B2	4.3 (oral)[e] 8.4 (inhal)[j]	OSHA-PEL: 0.002 mg/m^3, 0.005 mg/m^3 (ceiling) ACGIH-TLV: 0.002 mg/m^3 NIOSH-REL: 0.0005 mg/m^3, IDLH: 4 mg/m^3
Bismuth	7440-69-9	none found	none found	not classified	none found	none found
Boric acid	10043-35-3	$5.7x10^{-3}$[f]	0.02[g]	not classified	none found	PEL: 0.816 mg/m^3[m] LD50 (oral, rat): 2,660 mg/kg[i]

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
1,3-Butadiene	106-99-0	15.4[f]	53.9[g]	EPA Group B2[e]	1.8 (inhal)[j]	OSHA-PEL: 2,200 mg/m^3 ACGIH-TLV: 22 mg/m^3 NIOSH-REL: 4,500 mg/m^3
Butane	106-97-8	13.3[h]	46.55[g]	not classified	none found	NIOSH-REL: 1,900 mg/m^3 ACGIH-TLV: 1,900 mg/m^3 PEL: 1900 mg/m^{3m}
1-Butene	106-98-9	none found	none found	not classified	none found	none found
2-Butoxyethanol	111-76-2	1.68[f]	5.88[g]	not classified	none found	OSHA-PEL: 240 mg/m^3 (skin) ACGIH-TLV: 121 mg/m^3 NIOSH-REL: 24 mg/m^3 (skin) IDLH: 3,437 mg/m^3
n-Butyl alcohol (1-Butanol)	71-36-3	0.10[e]	0.35[g]	EPA Group D[e]	none found	OSHA-PEL: 300 mg/m^3 ACGIH-TLV: 152 mg/m^3 (skin, ceiling) NIOSH-REL: 150 mg/m^3 (skin), IDLH: 4,312 mg/m^3
Butyl lactate	138-22-7	0.21[f]	0.74[g]	not classified	none found	PEL: 30 mg/m^3 ACGIH-TLV: 30.0 mg/m^3 NIOSH-REL: 25.0 mg/m^3
Cadmium oxide (fume, as Cd)	1306-19-0	$3.5x10^{-5}$[f]	$1.23x10^{-4}$[g]	not classified	none found	OSHA-PEL: 0.005 mg/m^3 ACGIH-TLV: 0.05 mg/m^3 (ceiling) NIOSH-STEL: 9 mg/m^3
Cadmium dust (nonradionuclide)	7440-43-9	$5x10^{-4}$[e]	$1.75x10^{-3}$[g]	EPA Group B1[e]	$6.3x10^{-3}$[o] (Unit Risk: $1.8x10^{-6}$ mg/m^3)[n]	OSHA-PEL: 0.005 mg/m^3 ACGIH-TLV: 0.05 mg/m^3
Calcium	7440-70-2	none found	none found	not classified	none found	none found
Carbon dioxide	124-38-9	63[f]	221[g]	not classified	none found	OSHA-PEL: 9,000 mg/m^3 ACGIH-TLV: 9,000 mg/m^3, STEL: 54,000 mg/m^3 NIOSH-REL: 9,000 mg/m^3, STEL: 54,000 mg/m^3, IDLH: $7.3x10^4$ mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Carbon disulfide	75-15-0	0.1[e]	0.35[g]	not classified	none found	OSHA-PEL: 63.2 mg/m^3 ACGIH-TLV: 31 mg/m^3 (skin) NIOSH-REL: 3 mg/m^3, STEL: 30 mg/m^3, IDLH: 1,580 mg/m^3
Carbon monoxide	630-08-0	0.385[f]	1.35[g]	not classified	none found	OSHA-PEL: 55 mg/m^3 ACGIH-TLV: 29 mg/m^3 NIOSH-REL: 40 mg/m^3, IDLH: 1,392 mg/m^3
Carbon tetrachloride	56-23-5	$7x10^{-4}$[e]	$2.45x10^{-3}$[g]	EPA Group B2[e]	0.13 (oral) 0.053 (inhal)[j]	OSHA-PEL: 63.9 mg/m^3, 160 mg/m^3 (ceiling) ACGIH-TLV: 31 mg/m^3 (skin) NIOSH-STEL: 12.6 mg/m^3 IDLH: 1,278 mg/m^3
Chloride (Sodium chloride)	77647-14-5	0.12[l]	0.42[g]	not classified	none found	LD50: 3,000 mg/m^3[i] PEL: 17.1 mg/m^3[m]
Chlorine	7782-50-5	0.1[e]	0.35[g]	EPA Group D[k]	none found	OSHA-PEL: 3 mg/m^3 (ceiling) ACGIH-TLV: 1.5 mg/m^3, STEL: 2.9 mg/m^3 NIOSH-REL: 1.45 mg/m^3 (ceiling, 15 min.), IDLH: 29.5 mg/m^3
Chlorobenzene	108-90-7	0.02[e]	0.07[g]	EPA Group D[e]	none found	OSHA-PEL: 350 mg/m^3 ACGIH-TLV: 46 mg/m^3 NIOSH-REL: 4,680 mg/m^3
Chloroform	67-66-3	0.01[e]	0.035[g]	EPA Group B2[e]	$6.1x10^{-3}$ (oral)[e] 0.081 (inhal)[j]	OSHA-PEL: 240 mg/m^3 (ceiling) ACGIH-TLV: 49 mg/m^3 NIOSH-REL: 9.78 mg/m^3 (60 min), IDLH: 2,480 mg/m^3
bis-Chloromethyl ether	542-88-1	$3.29x10^{-5}$[r]	$1.15x10^{-4}$[g]	EPA Group A[e]	220[j]	PEL: 0.0047 mg/m^3[m] ACGIH-TLV: 0.0047 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Chromium (Hexavalent)	18540-29-9	$5x10^{-3}$	0.0175[g]	EPA Group A	41 (inhal)[j]	OSHA-PEL: 1 mg/m^3[i] ACGIH-TLV: 0.05 mg/m^3 (water soluble)
Chromium (Trivalent)	16065-83-1	1[e]	3.5[g]	not classified	none found	OSHA-PEL: 0.5 mg/m^3 ACGIH-TLV: 0.5 mg/m^3 NIOSH-REL: 0.5 mg/m IDLH: 25 mg/m^3
Cobalt (metal dust and fume)	7440-48-4	$7x10^{-4}$[f]	$2.45x10^{-3}$[g]	not classified	none found	OSHA-PEL: 0.1 mg/m^3 ACGIH-TLV: 0.05 mg/m^3 NIOSH-REL: 0.05 mg/m^3, IDLH: 20 mg/m^3
Copper (dusts and mists)	7440-50-8	0.007[f]	0.0245[g]	EPA Group D[e]	none found	OSHA-PEL: 1 mg/m^3 ACGIH-TLV: 1 mg/m^3 NIOSH-REL: 1 mg/m^3, IDLH: 100 mg/m^3
Cresol (m-cresol, cresylic acid)[p]	108-39-4	0.154[f]	0.539[g]	not classified	none found	OSHA-PEL: 22 mg/m^3 (skin) ACGIH-TLV: 22 mg/m^3 (skin, all isomers) NIOSH-REL: 10 mg/m^3, IDLH: 1,125 mg/m^3
Cyclohexane	110-82-7	7.35[f]	25.725[g]	not classified	none found	OSHA-PEL: 1,050 mg/m^3 ACGIH-TLV: 1,030 mg/m^3 NIOSH-REL: 1,050 mg/m^3, IDLH: 4,550 mg/m^3
Cyclohexanone	108-94-1	5[e]	17.5[g]	not classified	none found	OSHA-PEL: 200 mg/m^3 ACGIH-TLV: 100 mg/m^3 (skin) NIOSH-REL: 100 mg/m^3 (skin)
Cyclopentane	287-92-3	12.05[f]	42.18[g]	not classified	none found	OSHA-PEL: 1,721 mg/m^3[i] ACGIH-TLV: 1,720 mg/m^3 NIOSH-REL: 1,720 mg/m^3
Dibenzofuran	132-64-9	none found	none found	EPA Group D[e]	none found	none found

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Dibutyl phosphate	107-66-4	0.035[f]	0.1225[g]	not classified	none found	OSHA-PEL: 5 mg/m^3[i] ACGIH-TLV: 8.6 mg/m^3, STEL: 17 mg/m^3 NIOSH-REL: 5 mg/m^3 STEL: 10 mg/m^3
o-Dichlorobenzene (1,2-Dichlorobenzene)	95-50-1	0.09[e]	0.315[g]	EPA Group D	none found	OSHA-PEL: 300 mg/m^3 (ceiling) ACGIH-TLV: 150 mg/m^3, STEL: 301 mg/m^3 NIOSH-REL: 300 mg/m^3, IDLH: 1,222 mg/m^3
3,3-Dichlorobenzidine (and salts)	91-94-1	none found	none found	$B2^o$	o.45[e]	none found
Dichlorodifluoromethane	75-71-8	0.2[e]	0.7[g]	EPA Group D[k]	none found	OSHA-PEL: 4,950 mg/m^3 ACGIH-TLV: 4,950 mg/m^3 NIOSH-REL: 4,950 mg/m^3 IDLH: 75,450 mg/m^3
Dichloromethane (Methylene chloride)	75-09-2	0.06[e]	3.0[g]	EPA Group B2[e]	$7.5x10^{-3}$ (oral)[e]	OSHA-PEL: 1,765 mg/m^3, 3,530 mg/m^3 (ceiling) ACGIH-TLV: 174 mg/m^3 NIOSH-REL: 8,119 mg/m^3
Dimethylformamide (DMF)	68-12-2	$8.58x10^{-3}$[d]	0.03[e]	not classified	none found	OSHA-PEL: 30 mg/m^3 (skin) ACGIH-TLV: 30 mg/m^3 (skin) NIOSH-REL: 30 mg/m^3 (skin), IDLH: 1,520 mg/m^3
2,4,-Dinitrotoluene	25321-14-6	0.002[e]	0.007[g]	not classified	none found	OSHA-PEL: 1.5 mg/m^3 (skin) ACGIH-TLV: 0.15 mg/m^3 (skin) NIOSH-REL: 1.5 mg/m^3 (skin), IDLH: 50 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Di-sec octyl phthalate	117-81-7	0.02[q]	0.07[g]	not classified	none	OSHA-PEL: 5 mg/m^3 ACGIH-TLV: 5 mg/m^3, STEL: 10 mg/m^3 NIOSH-REL: 5 mg/m^3, STEL: 10 mg/m^3 IDLH: 5,000 mg/m^3
1,4-Dioxane	123-91-1	2.52[f]	8.82[g]	EPA Group B2	0.011[e]	OSHA-PEL: 360 mg/m^3 (skin) ACGIH-TLV: 90 mg/m^3 (skin) NIOSH-REL: 3.6 mg/m^3 (ceiling, 30-min), IDLH: 1,830 mg/m^3
Dodecane	112-40-3	none found	none found	not classified	none found	none found
Ethane	74-84-0	none found	none found	not classified	none found	none found
Ethyl acetate	141-78-6	0.9[e]	3.15[g]	not classified	none found	OSHA-PEL: 1,400 mg/m^3 ACGIH-TLV: 1,440 mg/m^3 NIOSH-REL: 1,400 mg/m^3, IDLH: 7,320 mg/m^3
Ethyl alcohol	64-17-5	13.3[f]	46.55[g]	not classified	none found	OSHA-PEL: 1,900 mg/m^3 ACGIH-TLV: 1,880 mg/m^3 NIOSH-REL 1,900 mg/m^3 IDLH: 6,336 mg/m^3
Ethyl benzene	100-41-4	0.1[e]	1.0[e]	EPA Group D[e]	none found	OSHA-PEL: 435 mg/m^3 ACGIH-TLV: 434 mg/m^3, STEL: 543 mg/m^3 NIOSH-REL: 435 mg/m^3, STEL: 545 mg/m^3 IDLH: 3,528 mg/m^3
Ethyl ether	60-29-7	0.2[e]	0.7[g]	not classified	none found	OSHA-PEL: 1,200 mg/m^3 ACGIH-TLV: 1,210 mg/m^3, STEL: 1,520 mg/m^3 IDLH: 5,852 mg/m^3
Ethylene	74-85-1	none found	none found	not classified	none found	none found

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Ethylene dichloride (1, 2-Dichloroethane)	107-06-2	1.44[f]	5.03[g]	EPA Group B2[e]	0.091 (oral)[e] 0.091 (inhal)[j]	OSHA-PEL: 205.5 mg/m^3, 411 mg/m^3 (ceiling) 822 mg/m^3 (5-min max peak any 3 hrs) ACGIH-TLV: 40 mg/m^3, NIOSH-REL: 4 mg/m^3, STEL: 8 mg/m^3 IDLH: 205.5 mg/m^3
Ethylene glycol	107-21-1	2.0[e]	7.0[g]	EPA Group D[k]	none found	ACGIH-TLV: 127 mg/m^3 (ceiling) PEL: 127 mg/m^{3m}
Ethylene glycol monoethyl ether (2-Ethoxyethanol)	110-80-5	5.18[f]	18.13[g]	not classified	none found	OSHA-PEL: 740 mg/m^3 (skin) ACGIH-TLV: 18 mg/m^3 (skin) NIOSH-REL: 1.8 mg/m^3 (skin), IDLH: 1,875 mg/m^3
Ethyltriacetyoxysilane	none	none	none	not classified	none found	none found
Fluoride	16984-48-8	0.0175[f]	0.061[g]	not classified	none found	OSHA-PEL: 2.5 mg/m^{3i} ACGIH-TLV: 2.5 mg/m^3
Formaldehyde	50-00-0	0.2[e]	0.7[g]	EPA Group B1[e]	0.045 (inhal)[j]	OSHA-PEL: 0.9375 mg/m^3, STEL: 2.5 mg/m^3 ACGIH-TLV: 0.37 mg/m^3 (ceiling) NIOSH-REL: 0.02 mg/m^3, 0.125 mg/m^3 (ceiling, 15 min.), IDLH: 25 mg/m^3
Formic Acid	64-18-6	0.063[f]	0.221[g]	not classified	none found	OSHA-PEL: 9 mg/m^3 ACGIH-TLV: 9.4 mg/m^3, STEL: 19 mg/m^3 NIOSH-REL: 9 mg/m^3, IDLH: 57.3 mg/m^3
n-Heptane	142-82-5	14[e]	49[g]	EPA Group D	none found	OSHA-PEL: 2,000 mg/m^3 ACGIH-TLV: 1,640 mg/m^3 STEL: 2,050 mg/m^3 NIOSH-REL: 350 mg/m^3 CEILING (15 min): 1,800 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
n-Hexane	110-54-3	0.06[d]	0.2[e]	EPA Group D[k]	none found	OSHA-PEL: 1800 mg/m^3 ACGIH-TLV: 176 mg/m^3 NIOSH-REL: 180 mg/m^3, IDLH: 3,938 mg/m^3
Hydrazine	302-01-2	9.31×10^{-3}[f]	3.26×10^{-2}[g]	EPA Group B2[e]	3.0 (oral)[e] 17 (inhal)[j]	OSHA-PEL: 1.33 mg/m^3 (skin) ACGIH-TLV: 0.13 mg/m^3 (skin) NIOSH-REL: 0.04 mg/m^3 (ceiling, 2 hr.), IDLH: 66.5 mg/m^3
Hydrochloric acid	7647-01-0	2×10^{-3}[d]	7×10^{-3}[e]	not classified	none found	OSHA-PEL: 7 mg/m^3 ACGIH-TLV: 7.5 mg/m^3 (ceiling) NIOSH-REL: 7 mg/m^3 IDLH: 76 mg/m^3
Hydrogen chloride	7647-01-0	2×10^{-3}[d]	7×10^{-3}[e]	not classified	none found	OSHA-PEL: 7 mg/m^3 ACGIH-TLV: 7.5 mg/m^3 (ceiling) NIOSH-REL: 7 mg/m^3 IDLH: 76 mg/m^3
Hydrogen cyanide	74-90-8	0.02[e]	0.07[g]	not classified	none found	OSHA-PEL: 11 mg/m^3 (skin) ACGIH-TLV: 11 mg/m^3 (skin, ceiling) NIOSH-REL: 5 mg/m^3 (skin), IDLH: 56 mg/m^3
Hydrogen fluoride	7664-39-3	0.06[q]	0.21[g]	not classified	none found	OSHA-PEL: 2.49 mg/m^3 ACGIH-TLV: 2.6 mg/m^3 (ceiling) NIOSH-REL: 2.5 mg/m^3, 5 mg/m^3 (ceiling, 15 min), IDLH: 24.9 mg/m^3
Hydrogen peroxide	7722-84-1	0.0098[f]	0.0343[g]	not classified	none found	OSHA-PEL: 1.4 mg/m^3 ACGIH-TLV: 1.4 mg/m^3 NIOSH-REL 1.4 mg/m^3 IDLH: 105.75 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Hydrogen sulfide	7783-06-4	$3x10^{-3}$[e]	$9x10^{-4}$[e]	not classified	none found	OSHA-PEL: 28.4 mg/m^3 (ceiling) ACGIH-TLV: 14 mg/m^3, STEL: 21 mg/m^3 NIOSH-REL: 15 mg/m^3 (ceiling, 10 min), IDLH: 142 mg/m^3
Iron (salts)	none found	0.007[r]	0.0245[g]	not classified	none found	PEL: 1 mg/m^{3m} ACGIH-TLV: 1 mg/m^3 NIOSH-REL: 1 mg/m^3
Isobutane	75-28-5	13.3[h]	46.55[g]	not classified	none found	PEL: 1900 mg/m^{3m} NIOSH-REL: 1900 mg/m^3
Isobutyl acetate	110-19-0	4.9[f]	17.15[g]	not classified	none found	OSHA-PEL: 700 mg/m^3 ACGIH-TLV: 713 mg/m^3 NIOSH-REL: 700 mg/m^3 IDLH: 6,279 mg/m^3
Isobutyl alcohol (isobutanol)	78-83-1	0.3[e]	1.05[g]	not classified	none found	OSHA-PEL: 300 mg/m^3 ACGIH-TLV: 152 mg/m^3 NIOSH-REL: 150 mg/m^3, IDLH: 4,928 mg/m^3
Isopropyl alcohol	67-63-0	6.9[q]	24.15[g]	not classified	none found	OSHA-PEL: 980 mg/m^3 ACGIH-TLV: 983 mg/m^3 STEL: 1,230 mg/m^3 NIOSH-REL: 980 mg/m^3 STEL: 1,225 mg/m^3 IDLH: 5,000 mg/m^3
Kerosene	8008-20-6	0.7[h]	2.45[g]	IARC Group 2A[i] (suspect carcinogen)	none found	NIOSH-REL: 100 mg/m^3
Lead	7439-92-1	$3.5x10^{-4}$[f]	$1.225x10^{-3}$[g]	EPA Group B2[e]	none found	OSHA-PEL: 0.05 mg/m^3 ACGIH-TLV: 0.15 mg/m^3 NIOSH-REL: 0.1 mg/m^3, IDLH: 100 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Lead chromate	7758-97-6	0.00035[r]	0.001225[g]	ACGIH Group A2[i] (suspect human carcinogen)	none found	OSHA-PEL: 0.05 mg/m^3[i] ACGIH-TLV (as Pb): 0.05 mg/m^3
Lithium	7439-93-2	none found	none found	not classified	none found	none found
Lithium hydride	7580-67-8	1.75×10^{-4}[f]	6.125×10^{-4}[g]	not classified	none found	OSHA-PEL: 0.025 mg/m^3 ACGIH-TLV: 0.025 mg/m^3 NIOSH-REL: 0.025 mg/m^3, IDLH: 0.5 mg/m^3
Magnesium (oxide fume)	1309-48-4	0.105[f]	0.368[g]	not classified	none found	OSHA-PEL: 15 mg/m^3 ACGIH-TLV: 10 mg/m^3 NIOSH-REL: 750 mg/m^3
Manganese	7439-96-5	1.43×10^{-5}[d]	5×10^{-5}[e]	EPA Group D[e]	none found	OSHA-PEL: 5 mg/m^3 (ceiling) ACGIH-TLV: 5 mg/m^3 (dust and compounds) NIOSH-REL: 1 mg/m^3, STEL: 3 mg/m^3, IDLH: 500 mg/m^3
Mercury (vapor)	7439-97-6	3×10^{-4} (inorganic, chronic)[j]	3×10^{-4}[q]	EPA Group D[e]	none found	OSHA-PEL: 0.1 mg/m^3 (ceiling) ACGIH-TLV: 0.05 mg/m^3 NIOSH-REL: 0.05 mg/m^3 (skin), IDLH: 10 mg/m^3
Methanol (methyl alcohol)	67-56-1	0.5[e]	1.75[g]	not classified	none found	OSHA-PEL: 260 mg/m^3 ACGIH-TLV: 262 mg/m^3 (skin), STEL: 328 mg/m^3 NIOSH-REL: 260 mg/m^3, STEL: 325 mg/m^3 (skin), IDLH: 7,980 mg/m^3
Methyl chloride	74-87-3	1.47[f]	5.145[g]	not classified	none found	OSHA-PEL: 210 mg/m^3 ACGIH-TLV: 103 mg/m^3 STEL: 207 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Methylene chloride (dichloromethane)	75-09-2	0.06[e]	3.0[q]	EPA Group B2[e]	$7.5x10^{-3}$ (oral)[e]	OSHA-PEL: 1,765 mg/m^3, 3,530 (ceiling) ACGIH-TLV: 174 mg/m^3 NIOSH-IDLH: 8,119 mg/m^3
Methyl ethyl ketone (MEK; 2-Butanone)	78-93-3	1.0[e]	1.0[e]	EPA Group D[e]	none found	OSHA-PEL: 590 mg/m^3 ACGIH-TLV: 590 mg/m^3, STEL: 885 mg/m^3 NIOSH-REL: 590 mg/m^3, STEL: 885 mg/m^3, IDLH: 9,000 mg/m^3
Methyl isobutyl ketone (hexone)	108-10-1	0.08 (chronic)[j]	0.28[g]	not classified	none found	OSHA-PEL: 410 mg/m^3 ACGIH-TLV: 205 mg/m^3, STEL: 307 mg/m^3 NIOSH-REL: 205 mg/m^3, STEL: 300 mg/m^3, IDLH: 2,085 mg/m^3
Naphthalene (napthene)	91-20-3	0.35[f]	1.225[g]	EPA Group D[e]	none found	OSHA-PEL: 50 mg/m^3 ACGIH-TLV: 52 mg/m^3, STEL: 79 mg/m^3 NIOSH-REL: 50 mg/m^3, STEL: 75 mg/m^3, IDLH: 1,333 mg/m^3
Nickel (refinery dust)	7440-02-0	0.007[f]	0.0245[g]	EPA Group A[e]	0.84 (inhal)[j]	OSHA-PEL: 1.0 mg/m^3 (metal and other compds.) ACGIH-TLV: 1 mg/m^3 NIOSH-REL: 0.015 mg/m^3
Nitric acid	7697-37-2	0.035[q]	0.1225[g]	not classified	none found	OSHA-PEL: 5 mg/m^3 ACGIH-TLV: 5.2 mg/m^3, STEL: 10 mg/m^3 NIOSH-REL: 5 mg/m^3, STEL: 10 mg/m^3, IDLH: 65.5 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Nitrobenzene	98-95-3	$5x10^{-4}$[e]	$1.75x10^{-3}$[g]	EPA Group D[e]	none found	OSHA-PEL: 5 mg/m^3 (skin) ACGIH-TLV: 5 mg/m^3 (skin) NIOSH-REL: 5.0 mg/m^3 (skin), IDLH: 1,024 mg/m^3
2-Nitropropane	79-46-9	$5.72x10^{-3}$[d]	0.02[e]	EPA Group B2[e]	9.4[j]	OSHA-PEL: 90 mg/m^3 ACGIH-TLV: 36 mg/m^3 IDLH: 370 mg/m^3
Octanol	111-87-5	0.72[l]	2.52[g]	not classified	none found	PEL: 102.8 LD50 (oral-rat) 18,000 mg/kg[i]
Oxalic acid	144-62-7	0.007[f]	0.0245[g]	not classified	none found	OSHA-PEL: 1 mg/m^3 ACGIH-TLV: 1 mg/m^3, STEL: 2 mg/m^3 NIOSH-REL: 1 mg/m^3, STEL: 2 mg/m^3, IDLH: 500 mg/m^3
Ozone	10028-15-6	$1.4x10^{-4}$[f]	$4.9x10^{-4}$[g]	not classified	none found	OSHA-PEL: 0.2 mg/m^3 ACGIH-TLV: 0.2 mg/m^3 NIOSH-REL: 0.2 mg/m^3 IDLH: 10 mg/m^3
Phenol	108-95-2	0.6[k]	2.1[g]	EPA Group D[e]	none found	OSHA-PEL: 19 mg/m^3 (skin) NIOSH-REL: 19 mg/m^3 (skin, ceiling, 15 min.)
Phosphoric acid	7664-38-2	0.007[f]	0.0245[g]	not classified	none found	OSHA-PEL: 1 mg/m^3 ACGIH-TLV: 1 mg/m^3, STEL: 3 mg/m^3 NIOSH-REL: 1 mg/m^3, STEL: 3 mg/m^3, IDLH: 1,000 mg/m^3
Phosphorus (yellow)	7723-14-0	$7x10^{-4}$[f]	$2.45x10^{-3}$[g]	not classified	none found	OSHA-PEL: 0.1 mg/m^3 ACGIH-TLV: 0.1 mg/m^3 NIOSH-REL: 0.1 mg/m^3, IDLH: 5 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Phosgene	75-44-5	$2.8x10^{-3}$[f]	$9.8x10^{-3}$[g]	not classified	none found	OSHA-PEL: 0.4 mg/m^3 ACGIH-TLV: 0.4 mg/m^3 NIOSH-REL: 0.4 mg/m^3, 0.8 mg/m^3 (ceiling, 15 min.) IDLH: 8.22 mg/m^3
Plutonium oxide (plutonium cmpds)	none found	none found	none found	not classified	none found	none found
Potassium chromate (VI)	7789-00-6	0.007[f]	0.0245[g]	not classified	none found	OSHA-PEL: 1.0 mg/m^3[i] NIOSH-REL: 0.05 mg/m^3
Potassium hydroxide	1310-58-03	0.014[f]	0.049[g]	not classified	none found	OSHA-PEL: 2 mg/m^3[i] ACGIH-TLV: 2 mg/m^3 (ceiling) NIOSH-REL: 2 mg/m^3
Propane	74-98-6	12.6[f]	44.1[g]	not classified	none found	OSHA-PEL: 1,800 mg/m^3 NIOSH-REL: 1,800 mg/m^3, IDLH: 3,843 mg/m^3
Propene	115-07-1	none found	none found	not classified	none found	none found
Propionaldehyde	123-38-6	0.056[l]	0.197[g]	not classified	none found	LD50 (oral, rat): 1,410 mg/kg[j] PEL: 8.06 mg/m^3[m]
Propylene oxide	75-56-9	1.68[f]	0.03[e]	EPA Group B2[e]	0.24[e]	OSHA-PEL: 240 mg/m^3 ACGIH-TLV: 48 mg/m^3
Pyrene	129-00-0	0.03[e]	0.105[g]	EPA Group D[e]	none found	OSHA-PEL: 0.2 mg/m^3[i]
Pyridine	110-86-1	0.001[e]	0.0035[g]	not classified	none found	OSHA-PEL: 15 mg/m^3 ACGIH-TLV: 16 mg/m^3 NIOSH-REL: 15 mg/m^3, IDLH: 3,290 mg/m^3
Selenium	7782-49-2	$5x10^{-3}$[e]	0.0175[g]	EPA Group D[e]	none found	OSHA-PEL: 0.2 mg/m^3 ACGIH-TLV: 0.2 mg/m^3 NIOSH-REL: 0.2 mg/m^3, IDLH: 1 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Silicon	7440-21-3	0.035[f]	0.1225[g]	not classified	none found	OSHA-PEL: 15 mg/m^3 (total), 5 mg/m^3 (resp) ACGIH-TLV: 10 mg/m^3 NIOSH-REL: 10 mg/m^3 (total), 5 mg/m^3 (resp)
Silver	7440-22-4	$5x10^{-3}$[e]	0.0175[g]	EPA Group D[e]	none found	OSHA-PEL: 0.01 mg/m^3 ACGIH-TLV: 0.1 mg/m^3 NIOSH-REL: 0.01 mg/m^3, IDLH: 10 mg/m^3
Stoddard solvent	8052-41-3	20.3[d]	71.05[f]	not classified	none found	OSHA-PEL: 2,900 mg/m^3 ACGIH-TLV: 525 mg/m^3 NIOSH-REL: 1,800 mg/m^3 (ceiling, 15-min) IDLH: 20,000 mg/m^3
Styrene	100-42-5	0.2[e]	1[e]	EPA Group C[k]	none found	OSHA-PEL: 433 mg/m^3, 866 mg/m^3 (ceiling) ACGIH-TLV: 213 mg/m^3 (skin), STEL: 426 mg/m^3 (skin) NIOSH-REL: 215 mg/m^3, STEL: 425 mg/m^3, IDLH: 3,031 mg/m^3
Sulfuric acid	7664-93-9	0.007[f]	0.0245[g]	not classified	none found	OSHA-PEL: 1 mg/m^3 ACGIH-TLV: 1 mg/m^3, STEL: 3 mg/m^3 NIOSH-REL: 1 mg/m^3, IDLH: 15 mg/m^3
Tetrachloroethylene	127-18-4	0.01[e]	0.035[g]	EPA Group C-B2[j]	0.002[j]	OSHA-PEL: 689 mg/m^3, 1,378 mg/m^3 (ceiling) ACGIH-TLV: 339 mg/m^3, STEL: 1,357 mg/m^3 NIOSH-STEL: 1,034 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Tetrahydrofuran (THF)	109-99-9	4.13[f]	14.455[g]	not classified	none found	OSHA-PEL: 590 mg/m^3 ACGIH-TLV: 590 mg/m^3, STEL: 737 mg/m^3 NIOSH-REL: 590 mg/m^3, STEL: 735 mg/m^3, IDLH: 6,000 mg/m^3
Titanium	7440-32-6	none found	none found	not classified	none found	none found
Toluene	108-88-3	0.2[e]	0.4[e]	EPA Group D[e]	none found	OSHA-PEL: 766 mg/m^3, 1,149 mg/m^3 (ceiling) ACGIH-TLV: 188 mg/m^3 (skin) NIOSH-REL: 375 mg/m^3, STEL: 560 mg/m^3, IDLH: 1,915 mg/m^3
Tributyl phosphate	126-73-8	0.035[d]	0.1225[g]	not classified	none found	OSHA-PEL: 5 mg/m^3 ACGIH-TLV: 2.2 mg/m^3 NIOSH-REL: 2.5 mg/m^3 IDLH: 332.1 mg/m^3
1,1,1-Trichloroethane (TCA; methyl chloroform)	71-55-6	0.035[k]	1.0	EPA Group D[e]	none found	OSHA-PEL: 1,900 mg/m^3 ACGIH-TLV: 1,910 mg/m^3, STEL: 2,460 mg/m^3 NIOSH-REL: 1,900 mg/m^3 (ceiling, 15 min.), IDLH: 3,885 mg/m^3
1,1,2-Trichloroethane	79-00-5	0.004[e]	0.014[g]	EPA Group C[e]	0.057 (oral)[e] 0.057 (inhal)[j]	OSHA-PEL: 45 mg/m^3 (skin) ACGIH-TLV: 55 mg/m^3 NIOSH-REL: 375 mg/m^3 (skin), IDLH: 555 mg/m^3
Trichloroethylene (TCE)	79-01-6	3.82[f]	13.377[g]	EPA Group B2[k]	6.0×10^{-3} (inhal)[j]	OSHA-PEL: 546 mg/m^3, 1,092 mg/m^3 (ceiling) ACGIH-TLV: 269 mg/m^3, STEL: 1,070 mg/m^3 NIOSH-IDLH: 5,460 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Trichlorotrifluoroethane (Freon 113)	76-13-1	30.0[e]	105.0[g]	not classified	none found	OSHA-PEL: 7,600 mg/m^3 ACGIH-TLV: 7,670 mg/m^3, STEL: 9,590 mg/m^3 NIOSH-REL: 7,600 mg/m^3, STEL: 9,500 mg/m^3, IDLH: 15,580 mg/m^3
1,2,4-Trimethylbenzene	95-63-6	0.875[h]	3.06[g]	not classified	none found	PEL: 125 mg/m^{3m} NIOSH-REL: 125 mg/m^3
Tungsten (insoluble compds)	7440-33-7	0.035[h]	0.1225[g]	not classified	none found	ACGIH-TLV: 5 mg/m^3 STEL: 10 mg/m^3 NIOSH-REL: 5 mg/m^3 STEL: 10 mg/m^3
VM&P naphtha	8032-32-4	2.45[h]	8.575[g]	not classified	none found	PEL: 245 mg/m^{3m} ACGIH-TLV: 1,370 mg/m^3 NIOSH-REL: 350 mg/m^3, 1,800 mg/m^3 (ceiling, 15 min)
Welding fumes	ZC2550000	0.035[r]	0.1225[g]	not classified	none found	TLV[i]: 5 mg/m^3

Table M.3.3–1. Table of Exposure Limits—Continued

Compound	Chemical Abstracts Service No.	Reference Dose (oral) (mg/kg/day)	Reference Concentration (inhalation) (mg/m^3)	Cancer Class[a]	Slope Factor $(mg/kg/day)^{-1}$	Occupational Exposure Levels[b,c]
Xylene (mixture)	1330-20-7	2.0[e]	7.0[g]	EPA Group D[e]	none found	OSHA-PEL: 435 mg/m^3 ACGIH-TLV: 435 mg/m^3, STEL: 651 mg/m^3 NIOSH-REL: 435 mg/m^3, STEL: 655 mg/m^3, IDLH: 3,969 mg/m^3
Zinc	7440-66-6	0.3[e]	1.05[g]	EPA Group D[e]	none found	PEL: 42.9 mg/m^{3m}

[a] EPA Groups for carcinogenicity are classified as follows[j]:
EPA Group A: Human Carcinogen;
EPA Group B1: Probable Human Carcinogen - limited evidence in human studies;
EPA Group B2: Probable Human Carcinogen - sufficient evidence from animal studies, inadequate evidence or no data from human studies;
EPA Group C: Possible Human Carcinogen;
EPA Group D: Not Classifiable as to Human Carcinogenicity

[b] OSHA and NIOSH exposure levels were taken from NIOSH 1994a.

[c] ACGIH exposure levels were taken from ACGIH nda.

[d] RfD calculated from RfC, formula from the Center for Risk Management, ORNL (ORNL 1992d).

[e] ORNL 1994a.

[f] RfD calculated from OSHA-PEL, formula from the Center for Risk Management, ORNL (ORNL 1992d).

[g] RfC calculated from RfD, formula from the Center for Risk Management, ORNL (ORNL 1992d).

[h] RfD calculated from NIOSH-REL.

[i] Lewis 1992a.

[j] EPA 1994b.

[k] EPA 1993a.

[l] RfD calculated from LD50 (RfD = LD50 x $4x10^{-5}$).

[m] PEL calculated from RfD.

[n] EPA 1993c.

[o] Slope Factor=Unit Risk $(\mu g/m^3)^{-1}$ x 70 kg x 10^3 $(\mu g/mg)/20(m^3/day)$ where: 70 kg is the average weight of an adult, 10^3 $(\mu g/mg)$ converts ug to mg, and 20 (m^3/day) is the estimated volume of air inhaled by an average adult.

[p] Mixture of three isomers (m, o, and p) in which the m-isomer predominates (Merck 1976a).

[q] PNL 1995a.

[r] RfD calculated from ACGIH-TWA, formula from the Center for Risk Management, Oak Ridge National Laboratories (ORNL 1992d).

M.3.4 HAZARDOUS CHEMICAL RISK/EFFECTS CALCULATIONS

Tables M.3.4–1 through M.3.4–79 show the human health risk increment from exposure to hazardous chemicals associated with the various alternative activities. The terms associated with calculations are given in the footnotes for each table so that each calculated value can be verified.

M.4 HUMAN HEALTH STUDIES: EPIDEMIOLOGY

Various epidemiologic studies have been conducted at some of the sites evaluated in this PEIS because of the concern for potential health effects (that is, premature fatalities) associated with the manufacture and testing of nuclear weapons. These studies focus on the DOE workforce and residents of communities, surrounding DOE sites.

M.4.1 BACKGROUND

The health effects associated with ionizing radiation exposure were first published about 60 years ago. Studies published in the 1930s first documented cancer among painters who used radium to paint watch dials back in 1910-1920. Radiation therapy for disease was used since the 1930s, and studies have shown that the risk of cancer was related to the amounts of radiation received. Nuclear weapons research and manufacture and consequent exposure to radiation occurred beginning in the late 1930's. Exposure to radionuclides has changed over time with higher levels occurring in the early days of research and production. Numerous epidemiologic studies have been conducted among workers who manufactured and tested nuclear weapons due to the concern with potential adverse health effects. More recently, concerns about radiologic contaminants off-site have resulted in health studies among communities that surround DOE facilities. The following section briefly gives an overview of epidemiology followed by a review of epidemiologic studies of sites evaluated in the PEIS.

Epidemiology is the study of the distribution and determinants of disease in human populations. The distribution of disease is considered in relation to time, place, and person. Relevant population characteristics should include the age, race and sex distribution of a population, as well as other characteristics related to health, such as social characteristics (for example, income and education), occupation, susceptibility to disease, and exposure to specific agents. Determinants of disease include the causes of disease, as well as factors that influence the risk of disease.

M.4.1.1 Study Designs

Ecologic Studies. Ecologic studies compare the frequency of a disease in groups of people in conjunction with simple descriptive studies of geographical information in, an attempt to determine how health events among populations vary with levels of exposure. These groups may be identified as the residents of a neighborhood, a city, or a county where demographic information and disease or mortality data are available. Exposure to specific agents may be defined in terms of residential location or proximity to a particular area, such as distance from a waste disposal site. An example of an ecologic study is a comparison of the rate of heart disease among community residents by drinking water quality.

The major disadvantage of ecologic studies is that the measure of exposure is based on the average level of exposure in the community, when we are really interested in the individual's exposure. Ecologic studies do not take into account other factors, such as age and race that may also be related to disease. These types of studies may lead to incorrect conclusions, an "ecologic fallacy." For the above example, it would be incorrect to assume that the level of water hardness influences the risk of getting heart disease. Despite the obvious problems with ecologic studies, they can be a useful first step in identifying possible associations between risk of disease and environmental exposures. However, because of their potential for bias they should never be considered more than an initial step in investigation of disease causation.

Cohort Studies. The cohort study design is a type of epidemiologic study frequently used to examine occupational exposures within a defined workforce. A cohort study requires a defined population that can be classified as being exposed or not exposed to an agent of interest, such as radiation or chemicals that influence the probability of occurrence of a given disease. Characterization of the exposure may be qualitative (for example, high, low, or no exposure) or very quantitative (for example, radiation measured in Sieverts [Sv] and

chemicals in parts per million). Surrogates for exposure, such as job titles, are frequently used in the absence of quantitative exposure data.

Individuals enumerated in the study population are followed for a period of time to observe who died. In general overall rates of death and cause-specific rates of death have been assessed for workers at the PEIS sites. Death rates for the exposed worker population are compared with death rates of workers who did not have the exposure (internal comparison), or compared with expected death rates based on the U.S. population or State death rates (external comparison). If the rates of death differ from what is expected, an association is said to exist between the disease and exposure. In cohorts where the exposure has not been characterized, excess mortality can be identified, but these deaths cannot be attributed to a specific exposure, and additional studies may be warranted. More recent studies have looked at other disease endpoints, such as overall and cause-specific cancer incidence (newly diagnosed) rates.

Most cohort studies at PEIS sites have been historical cohort studies, that is, the exposure occurred some time in the distant past. These studies rely on past records to document exposure. This type of study can be problematic if exposure records are incomplete or were destroyed. Cohort studies require extremely large populations that have been followed for many (20-30) years. They are generally difficult to conduct and are very expensive. These studies are not well suited to studying diseases that are rare. Cohort studies do, however, provide a direct estimate of the risk of death from a specific disease, and allow an investigator to look at many disease endpoints.

Case-Control Studies. The case-control study design starts with the identification of persons with the disease of interest (case) and a suitable comparison (control population of persons without the disease). Controls must be persons who are at risk for the disease and are representative of the population that generated the cases. The selection of an appropriate control group is often quite problematic. Cases and controls are then compared with respect to the proportion of individuals exposed to the agent of interest. Case-control studies require fewer persons than cohort studies, and therefore, are usually less costly and less time consuming, but are limited to the study of one disease (or cause of death). These types of studies are well suited for the study of rare diseases and are generally used to examine the relationship between a specific disease and exposure.

M.4.1.2 Definitions

Unfamiliar terms frequently used in epidemiologic studies, including those used in this document, are defined below.

Age, gender, and cigarette smoking are the principal determinants of mortality. Standardization is a statistical method used to control for the effects of age, gender, or other characteristics so that death may be compare among different population groups. There are two ways to standardize rates, the indirect or direct methods. In general the indirect method of standardization is most frequently used.

Indirect standardization: The disease rates in the reference (comparison) population are multiplied by the number of individuals in the same age and gender group in the study population to obtain the expected rate of disease for the study population.

Direct standardization: The disease rates in the study population are multiplied by the number of individuals in the same age and gender group in the reference (comparison) population. This gives the expected rates of disease for the reference population if these rates had prevailed in that group.

Standardized mortality ratio (SMR): The SMR is the ratio of the number of deaths observed in the study population to the number of expected deaths. The expected number of deaths is based on a reference (or comparison population). Death rates for the U.S. population (or State) are most frequently used as the comparison to obtain expected rates. An SMR of 1 indicates a similar risk of disease in the study population

compared with the reference population. An SMR greater than 1 indicates excess risk of disease in the study population compared with the reference group, and an SMR less than 1 indicates a deficit of disease.

[Text deleted.]

Relative risk: The ratio of the risk of disease among the exposed population to the risk of disease in the unexposed population. Relative risks are estimated from cohort studies.

Odds ratio: The ratio of the odds of disease if exposed, to the odds of disease if not exposed. Under certain conditions, the odds ratio approaches the relative risk. Odds ratios are estimated from case-control studies.

Excess Relative Risk (ERR): Per SV is based on a regression model in which the relative risk is assumed to be of the form $1 + \beta Z$, where Z is the cumulative dose in SV.

Standardized Rate Ratio (SRR): A rate ratio in which the numerator and the denominator have been standardized to the same (standard) population distribution.

[Text deleted.]

Healthy Worker Effect: A phenomenon observed in studies of occupational diseases. Workers usually exhibit lower overall death or disease rates compared to the general population, due to the fact that the severely ill and disabled are excluded from employment. Rates from the general population may be inappropriate for comparison if this effect is not taken into consideration.

Confidence Interval (CI): A range of values for a variable of interest, for example, a rate, constructed so that this range has a specified probability of including the true value of the variable. The specified probability is called the confidence level, and the end points of the confidence interval are called the confidence limits.

P, P (Probability) Value: The probability that a test statistic would be as extreme as or more extreme than observed if the null hypothesis were true. The letter P, followed by the abbreviation n.s. (not significant) or by the symbol < (less than) and a decimal notation such as 0.01, 0.05, is a statement of the probability that the difference observed could have occurred by chance, if the groups are really alike, that is, under the *Null Hypothesis*. Investigators may arbitrarily set their own significance levels, but in most biomedical and epidemiologic work, a study result whose probability value is less than 5 percent ($P < 0.05$) or 1 percent ($P < 0.01$) is considered sufficiently unlikely to have occurred by chance to justify the designation "statistically significant."

Multivariate Analysis: A set of techniques used when the variation in several variables has to be studied simultaneously. In statistics, any analytic method that allows the simultaneous study of two or more *Dependent Variables*.

Incidence: (*Syn:incident number*) The number of instances of illness commencing, or of persons falling ill, during a given period in a specified population. More generally, the number of new cases of a disease in a defined population, within a specified period of time. The term incidence is sometimes used to denote *Incidence Rate*.

Incidence Rate: The rate at which new events occur in a population. The numerator is the number of new events that occur in a defined period; the denominator if the population at risk of experiencing the event during this period, sometimes expressed as person-time. The incidence rate most often used in public health practice is calculated by the formula

$$\frac{\text{Number of new events in specified period}}{\text{Number of persons exposed to risk during this period}} \times 10^n$$

In a dynamic population, the denominator is the average size of the population, often the estimated population at the mid-period. If the period is a year, this is the annual incidence rate. This rate is an estimate of the person-time incidence rate, that is, the rate per 10^n person-years. If the rate is low, as with many chronic diseases, it is also a good estimate of the cumulative incidence rate. In follow-up studies with no censoring, the incidence rate is calculated by dividing the number of new cases in a specified period by the initial size of the cohort of persons being followed; this is equivalent to the cumulative incidence rate during the period. If the number of new cases during a specified period is divided by the sum of the person-time units at risk for all persons during the period, the result is the person-time incidence rate.

[Text deleted.]

M.4.2 HANFORD SITE

Surrounding Community

Sever et al. published two studies in 1988 of birth defects in Benton and Franklin Counties in which Hanford is located (AJE 1988a:226-242, 243-254). The prevalence of births of congenital malformed infants for the study period from 1968 to 1980 was the focus of one of the two studies (AJE 1988a:243-254). The congenital malformation rate in the newborn population of 19.6/1000 was not elevated compared with the rates for the States of Washington, Idaho, and Oregon (12.2 / 1000). Neural tube defects were more common than expected in the comparison area (Prevalence=1.72; 95% CI=1.22-2.34). The companion case-control study investigated whether there was any association of parental occupational exposure to external radiation and the risk of congenital malformations among births occurring from 1957 to 1980 (AJE 1988a:226-242). Two defects, congenital dislocation of the hip (12 observed, 7.1 expected, $p<0.025$) and tracheoesophageal fistula (4 observed, 1.4 expected, $p<0.05$), showed statistically significant association with parental employment at Hanford but not with parental radiation exposure.

Neural tube defects showed a significant association with parental preconception external radiation exposure. Other defects studied, including Down's Syndrome, showed no evidence of such an association with parental external radiation exposure.

Jablon et al. examined cancer mortality in populations living near nuclear facilities in the U.S., including Hanford (JAMA 1991a:1403-1408). The study compared cancer mortality in 107 counties with or near 62 nuclear facilities to those in comparison counties with similar demographic characteristics but without nuclear facilities. For Hanford, Benton, Franklin, and Grant Counties were studied. The authors concluded that no general association was detected between residents in a county with a nuclear facility and death attributable to leukemia or any other form of cancer. The authors also noted that interpretation of the study results is limited by the study's ecological approach in which the exposures of individuals are not known.

Worker Studies

Mancuso and Sanders Era

Studies of the Hanford workers began in 1969. Initially, the study of Hanford workers conducted by the University of Pittsburgh was designed to evaluate longevity and disability in workers (HP 1978a:521-538). Hanford workers were compared with their brothers or sisters and to a national sample of employed people from the Social Security Administration continuous work history files. The study included 17,600 males and 3,900

females hired from 1944 through 1971, and considered deaths that occurred from 1944 to October 1972. Workers were categorized as "radiation exposed workers" and "nonexposed workers." In general, the longevity for both males and females within each category were similar, with the largest difference for exposed men who had a nonsignificantly reduced longevity relative to their sibling controls. A second analysis included about 1,800 Hanford workers; 1,800 matched Social Security Administration continuous work history controls; and 3,055 "identified siblings." The disability claim rate for all Hanford workers was significantly lower than the matched Social Security Administration continuous work history controls, as was the rate for radiation-exposed workers.

Analyses were expanded to examine specific causes of death (HP 1977a:369-385). In these analyses, the average cumulative radiation dose for workers dying of a site specific cancer, or group of cancers, was compared with the average radiation dose for all workers dying from all causes.

For deaths from 1944-1972, the following cancer types were reported with higher radiation doses: multiple myeloma, pancreas, brain, kidney, lung, colon, myeloid leukemia, and lymphomas. When the comparison was made against the average dose for all noncancer deaths rather than for all deaths, excess deaths were attributed to radiation for all cancers combined, multiple myeloma, myeloid leukemia, pancreas, and lung.

The authors examined the amount of radiation necessary to double the risk of death for specific cancers. Five cancer categories were concluded to have significant doubling doses: bone marrow cancers, pancreatic cancer, lung cancer, reticuloendothelial neoplasms, and all cancers combined. Next, the authors explored whether the doses received at some specific ages were more important than at other ages, and they concluded that sensitivity to radiation carcinogenesis was high before age 25 years and after age 45 years.

As the analytic methods used in the study were controversial, the Hanford data were re-analyzed by other investigators in 1979, and the analytic methods were reassessed. Hutchinson et al. concluded that analyses of the Hanford data, adjusted for age and calendar year of death, reduced the number of cancer sites for which a radiation dose relationship could be suggested to two: cancer of the pancreas ($p=0.011$ for trend test) and multiple myeloma ($p=0.009$ for trend test) (HP 1979a:207-220). For both of these sites, more deaths were observed than expected only among those with doses exceeding 10 rad. The authors also considered the issue of sensitive ages for radiation exposure and concluded such ages could not be identified without considering lifetime patterns of exposure ages.

In a separate independent analysis, Gofman et al. considered these issues using a different methodological approach (HP 1979a:617-639). The authors reported, consistent with the finding of Hutchinson et al., that differences in radiation dose between those dying of cancer compared with other diseases are found primarily in those receiving 10 rad or more exposure. The authors estimated that radiation caused a 3.5 percent increment in cancer deaths. The doubling dose for cancers overall was estimated at 43.5 rad, consistent with the Mancuso estimate previously reported. The authors did not concur with Mancuso et al. on the suggestion of variation in sensitivity to radiation by age at exposure.

Other methodological problems in the original analyses were identified by Anderson who concluded that the estimate of excess deaths was "implausible," but did agree that the analyses were consistent with some excess deaths from multiple myeloma, cancer of the pancreas, and possibly lung cancer (HP 1978b:743-750). A deficit in leukemia deaths was noted. The Mancuso study was also reviewed by the National Radiological Protection Board (NRPB) in the United Kingdom. This report concluded that the only excess fatal malignancies at Hanford that may be associated with radiation are cancer of the pancreas and multiple myeloma (NRPB 1978a). The report indicated that further investigation was necessary, as the effect could have been due to other carcinogens.

In 1978, Kneale, Stewart, and Mancuso updated the Hanford study with death information to 1977 (IAEA 1978a:387-412). The authors concluded that approximately 5 percent of the cancer deaths at Hanford were

radiation- induced and that these extra deaths were probably concentrated among cancers of the bone marrow, lung, and pancreas.

In 1981, Kneale et al. again reported on the Hanford data, using a different analytic technique (BJIM 1981a:156-166). The cohort included radiation-monitored employees up to 1975 and deaths through 1977. The authors estimated a linear model doubling dose at 15 rads, estimated the latency to be 25 years, and rejected the hypothesis that all age at exposure groups are equally sensitive to radiation.

In 1993, Kneale and Stewart published a re-analysis of the Hanford data (AJIM 1993a:371-389). The study included 27,395 male and 8,473 female workers who worked between 1944 and 1978 and had been monitored for radiation. Deaths were determined through 1986. In this analysis, all cancers listed on the death certificate were included in the study. The authors concluded that the Hanford data supported a doubling dose from 8.6 to 44.8 mSv, with a nonlinear dose response, in contrast to the prior study. The estimated proportion of radiation-caused cancers ranged from 12.5 percent to 50.9 percent, the cancer latency period was estimated to be 14-17 years, and the most radiosensitive ages for exposure were over 58 years of age.

In 1996, Stewart and Kneale again investigated the relationship between age at exposure and cancer risk in the Hanford data using monitored workers described in the 1993 analysis (OEM 1996a:225-230). The data were adjusted to account for the effects of date of birth and date of death. The workers were grouped by average doses into intervals of when dose was received to allow for cancer latency and age groups to isolate the most sensitive age at exposure.

The authors concluded that sensitivity to carcinogenic effects of radiation increase progressively with age during adult life and providing that the dose is too small to produce many cell deaths, the ratio of leukemias to solid tumors is no different for radiogenic and idiopathic tumors in contrast with the atomic bomb survivor data, which found a strong association with leukemia.

Simultaneously, other researchers were reporting the results of studies of the Hanford workers. In 1979, Gilbert and Marks reported the results of analyses of the mortality experience of Hanford workers from the time the plant was built through April 1974 (RR 1979a:122-148). The cohort consisted of 20,842 white males hired before 1966 with a focus on 13,075 employed at least 2 years. Mortality rates were not higher than expected among workers for all causes of death, all malignant neoplasms, diseases of the circulatory system, accidents, or other causes. When individual cancer sites were considered, only malignant neoplasm of the pancreas (SMR=130, $p<0.05$) among individuals who had worked less than 2 years at Hanford was significantly elevated.

To determine if there was an association with external radiation exposure, the mortality experience of workers who had been monitored for radiation was compared with all workers in the study. Among white males monitored for radiation, there was a statistically significant trend between mortality and increasing radiation dose for pancreatic cancer (4 observed, 2.5 expected; $p=0.07$ for trend test) and multiple myeloma (12.4 observed, 3.6 expected; $p=0.006$ for trend test) when lagged 2 years for cancer development. When exposures were lagged for 10 years, only deaths due to multiple myeloma (6.2 observed, 1.5 expected; $p=0.006$ for trend test) showed a trend with cumulative occupational exposure to ionizing radiation.

The mortality experience of the Hanford cohort was updated the following year (RR 1980a:740-741). Three hundred and ninety additional deaths among white males, occurring to May 1977, were included in the study. Results were similar to those previously reported.

The cohort was again updated in 1983 (RR 1983a:211-213). This analysis was expanded to include workers hired during and after 1965 and employed 2 or more years. In this analysis, the significant positive trend between increasing dose and pancreatic cancer disappeared. The significant trend for multiple myeloma remained.

The next update of the cohort mortality study for Hanford was published in 1989 (HP 1989a:11-25). The cohort consisted of 31,500 males and 12,600 females first employed through 1978. Deaths from 1944-1981 were analyzed for the entire cohort. Death certificates for radiation-monitored workers who died in the State of Washington between 1982-1985 were also obtained.

Overall, Hanford workers continued to have death rates substantially below the general U.S. population. Among female workers not monitored for external radiation, there were significantly more deaths for the category of accidents, poisonings, and violence than expected (SMR=1.38, p=0.05). Monitored females had a higher rate of death from diseases of the musculoskeletal system and connective tissues than expected (SMR=2.33, p=0.05). When individual cancer sites were considered, males not monitored for radiation were observed to have significantly higher rates of death from pancreatic cancer (SMR=1.69, p=0.01) and solid tumors (SMR=1.56, p=0.05) than expected.

The risk analyses for trends by radiation dose were lagged for 2- and 10-year induction periods, and included deaths from 1947 through 1981. No correlation between mortality and dose was seen when the analyses were lagged for 2 years. When dose was lagged 10 years, there was a suggestive trend between dose and deaths from all cancers, genital cancer among females, and multiple myeloma.

Although the number of workers at Hanford with Pu deposition was limited, data on these workers were analyzed separately to examine major cause of death categories by exposure categories. No trends between increasing death rates and increasing deposition Pu were detected. As cause of death information was available through 1985 for those dying in the State of Washington, additional analyses were conducted. Four additional deaths from multiple myeloma were observed, but the trend with dose was not statistically significant.

The Hanford cohort was once again updated by Gilbert et al. in 1993 (HP 1993a:577-590). This analysis included workers who were employed 6 months or more and were first employed through 1978. Deaths among the entire cohort that occurred from 1944 through 1986, and through 1989 for monitored workers who died in the State of Washington, were analyzed. This data set included 456 workers not previously studied and eliminated 265 individuals who never actually worked at the site. Radiation dose records from construction worker files were also added to the data set.

When the death rates for Hanford workers were compared with the general U.S. population, monitored females continued to have an elevated rate of deaths from musculoskeletal system and connective tissue conditions (SMR=2.06, p=0.05) noted in the 1989 paper. As previously reported, unmonitored males continued to have higher death rates for pancreatic cancer (SMR=1.57, p=0.05) and the category noted as miscellaneous solid tumors (SMR=1.47, p=0.05).

As in previous papers, the data were then analyzed to examine trends between the risk of death and external radiation dose lagged for 2 and 10 years. Statistically significant trends were seen when the dose was lagged 10 years for deaths due to pancreatic cancer (SMR=1.59, p=0.065), Hodgkin's disease (SMR=1.80, p=0.038), and multiple myeloma (SMR=1.54, p=0.10). Deaths due to liver cancer (SMR=1.93, p=0.065) were detected when the exposures were lagged for 2 years. Additional analyses were conducted, which included "all" cancers noted on the death certificate, in addition to those reported on the death certificate as the "underlying cause of death." The investigators concluded that there were no additional cancers that showed significant correlations with dose as compared with the previous analysis that used the underlying cause of death.

Hanford workers have been included in several studies that have examined occupational risks across the nuclear complex, both in the U.S. and internationally. These combined studies have been undertaken in an attempt to increase the statistical power of the studies to detect the effects of low-level chronic radiation exposure.

A combined site mortality study included workers from Hanford, Oak Ridge, and Rocky Flats (RR 1993a:408-421). Earlier analyses of these cohorts indicated that risk estimates calculated through

extrapolation from high-dose data to low-dose data did not seriously underestimate risks of exposure to low-dose radiation (AJE 1990a:917-927; RR 1989a:19-35). The updated analyses were performed in order to determine whether the extrapolated risks represented an over-estimation of the true risk at low doses. The study population consisted of white males employed at one of the three facilities for at least 6 months and monitored for external radiation. The Hanford population also included females and nonwhite workers. The total population dose was 1237 Sv. Analyses included trend tests for site-specific cancer deaths and several broad noncancer categories. Statistically significant trends were noted for cancer of the esophagus (p=0.015 for trend test), cancer of the larynx (p=0.019 for trend test), and Hodgkin's disease (p=0.048 for trend test). These cancers were not related to radiation exposure levels in previously published studies. Excess relative risk models were calculated for the combined DOE populations and for each DOE site separately. Without exception, all risk estimates included the possibility of zero risk (that is, the confidence interval for the risk coefficient went from below zero to above zero). There was evidence of an increase in the excess relative risk for cancer with increasing age in the Hanford and Oak Ridge populations; both populations showed significant correlations of all cancer with radiation dose among those 75 years and older.

Multiple myeloma (p=0.103 for trend test) was the only cancer found to exhibit a statistically significant correlation with radiation exposure that was based on the excess previously reported among Hanford workers.

An international effort to pool data from populations exposed to external radiation included Hanford workers, as well as workers at Rocky Flats and Oak Ridge in the U.S. and other radiation worker populations in Canada and Britain (RR 1995a:117-132). The cohort compared 95,673 workers employed 6 months or longer and the population dose was 3,543.2 Sv. There was no evidence of an association between radiation dose and mortality from all causes or from all cancers. There was a significant dose-response relationship with leukemia, excluding chronic lymphocytic leukemia (ERR=2.18 per Sv; 90 percent CI 0.1-5.7) and multiple myeloma (ERR not computed; 44 observed; p=0.037 for trend test). The study results do not suggest that current radiation risk estimates for cancer at low levels of exposure are appreciable in error.

Epidemiologic Studies

DOE's Office of Epidemiologic Studies has implemented an epidemiologic surveillance program at Hanford to monitor the health of current workers. This program will evaluate the occurrence of illness and injury in the workforce on a continuing basis and the results will be issued in annual reports. The implementation of this program will facilitate an ongoing assessment of the health and safety of Hanford's workforce and will help identify emerging health issues.

Currently operational at a number of DOE sites, including production sites and research and development (R&D) facilities, epidemiologic surveillance uses routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and OSHA recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data for an extended period of time become available, time trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring the health of the workforce provides a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate the need for more detailed study or increased health and safety measures to ensure adequate protection for workers.

Memorandum of Understanding

The Hanford Environmental Dose Reconstruction (Hanford Environmental Dose Reconstruction) Project was undertaken by DOE to estimate the radiation dose that people may have received from nuclear operations at

Hanford (WA Ecology 1994a). In 1990, DOE entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites. The Centers for Disease Control and Prevention's National Center for Environmental Health is responsible for dose reconstruction studies and has managed the Hanford Environmental Dose Reconstruction Project since that time.

The study determined that the largest doses to offsite populations were from iodine-131 released into the air in large quantities between December 1944 and December 1947. The most important radiation exposure pathway for iodine-131 was the consumption of milk produced by cows grazing on pasture downwind of Hanford. The doses to the thyroid gland of individuals near Hanford were larger than those farther from the site, and depended on the iodine-131 deposition and quantity of milk consumed at each location.

A second pathway of potential importance was the Columbia River. Releases to the river from Hanford were highest in the years 1956-1965, which was the height of reactor operations at Hanford. The most important means of exposure from the river pathway was the consumption of fish by local residents. However, maximum doses for the heaviest consumption of fish were estimated to be about half the dose an individual normally receives each year from all sources of radioactive materials in the U.S. environment. This study is in its final stages and will be completed shortly.

A study in the United Kingdom linked a father's exposure to ionizing radiation in the workplace with the subsequent risk of leukemia in his children (RR=6.42; 95 percent CI=1.57-26.3) (BMJ 1990a:423-434). A study was undertaken to replicate this study in other similar populations. Hanford was one of three sites selected for study by NIOSH. The population under study consists of residents of Benton and Franklin Counties. The study includes leukemia, non-Hodgkin's lymphoma, and central nervous system tumors diagnosed from 1957-1991 in children under the age of 15. The study is expected to be completed in 1996.

A number of studies of the Hanford workforce are underway, directed by NIOSH, under the Memorandum of Understanding.

Researchers at the University of Texas Medical Branch are conducting a cohort mortality study of female nuclear weapons workers exposed to low levels of ionizing radiation and other workplace physical and chemical agents at 12 DOE facilities, including Hanford. The study will be completed in 1997.

A study of multiple myeloma among workers exposed to ionizing radiation and other physical and chemical agents is being conducted by the University of North Carolina at various DOE sites, including Hanford. The study is expected to be completed in 1996-1997.

An epidemiologic evaluation of childhood leukemia and paternal exposure to ionizing radiation is being conducted by Battelle Columbus. The study will collect information of selected childhood cancers, residential history, and the father's exposure to ionizing radiation. Completion of the study is expected in 1996-1997.

An epidemiologic study of leukemia at four DOE sites is being conducted by NIOSH. Sites selected for the study include Hanford.

Boston University is conducting a health-effects-of-job-stress study associated with the redesign and reconfiguration of the nuclear weapons industry. This study will identify how specific practices for managing change affect individual health and work performance and to recommend ways to minimize health effects in the future. Hanford is one of seven DOE facilities included in this multisite study. The study will begin in 1996 and is scheduled for completion in 1999.

A comprehensive occupational health surveillance project at Hanford will design and implement a health surveillance system at the site. The University of Washington and the Hanford Environmental Health Foundation will conduct the study. Completion is expected in 1998.

A study of heat stress among carpenters at Hanford will assess the real effects of heat stress on physiologic functions in a real work situation. The study is being conducted by Michigan State University and the United Brotherhood of Carpenters' Health and Safety Fund. The study is scheduled for completion in 1999.

Other Related Studies

The Hanford Thyroid Disease Study began in 1988 under the management of Centers for Disease Control and will be completed in 1998 (HF FHCRC 1995a). It was initiated based on preliminary information from the Hanford Environmental Dose Reconstruction Project indicating that releases of radioactive iodine-131 from Hanford in its early years may have produced exposures to human thyroids large enough to have affected the gland's functioning. About 3,200 people living at various distances from Hanford have been located and are now being examined for thyroid disease and thyroid function. These people were selected because as infants during the years of peak releases of iodine-131 they were the most sensitive population group. Information gathered from the individuals in the study about their diet, milk consumption, age, sex, and place of residence will be used to calculate individual doses received by the thyroid gland using the models developed in the Hanford Environmental Dose Reconstruction Project. The study results are expected in 1998.

M.4.3 NEVADA TEST SITE

Surrounding Communities. Above ground testing of nuclear weapons at the NTS Test Range Complex in southern Nevada between 1951 and 1958 resulted in the dissemination of radioactive fallout over southeastern Nevada and southwestern Utah through wind dispersion. Several epidemiologic studies have been conducted to investigate possible health effects of low-level radiative fallout on residents of these States. These studies focused on leukemia and thyroid disease in children downwind of NTS.

A series of ecologic studies showed equivocal results in potentially exposed children. A cross sectional review of thyroid modularity among teenage children reported by Weiss et al. found no significant difference in the frequency of nodules among "potentially exposed" and "not exposed" children (AJPH 1971a:241-249). Exposure was defined in terms county of residence. Rallison et al. reported no significant difference in any type of thyroid disease between Utah children exposed to fallout radiation in the 1950s and control groups drawn from Utah and Arizona (AJM 1974a:457-463; JAMA 1975a:1069-1072).

To investigate the possible relationship between childhood leukemia and radioactive fallout, Lyon et al. conducted a mortality study of Utah-children under 15 years old who died in Utah between 1944 and 1975 (NEJM 1979a:397-402). Lyon et al. selected this age group because of the reported increased susceptibility of children to the neoplastic effects of radiation and the lack of a comparison group over 14 years of age with suitable low exposures. Lyon et al. obtained death certificates from the Utah vital statistics registrar and based on year of death, categorized decedents into either high (fallout years of 1951-1958) or low exposure periods (combined pre-fallout years of 1944-1950 and post-fallout years of 1959-1975). From estimated fallout patterns contained in maps of 26 tests, Lyon et al. categorized 17 southern rural counties high fallout area and the remaining northern urban counties as low fallout areas. Age-specific mortality rates derived for deaths which occurred in the combined low exposure periods were compared with those in the high exposure period. For reasons unknown, leukemia mortality during the low exposure periods in high fallout counties was half that of the United States and Utah. A significant excess of leukemia occurred among children statewide who died during the high fallout period compared to those who died during the low fallout periods (SMR=1.40, 95 percent CI=1.08-1.82, $p<0.01$). This excess was more pronounced among those who resided in the high fallout area (SMR=2.44, 95 percent CI=1.18-5.03). No pattern was found for other childhood cancers in relation to fallout exposure. A radiation dosage was not available, and the effect of migration were not determined for this study.

Beck and Krey reconstructed exposure of Utah residents studied by Lyon et al. (Science 1983a:18-24) to external gamma-radiation from NTS fallout through measurements of residual cesium-137 and Pu in soil

(NEJM 1979a:397-402). Beck and Krey found that residents in southwest Utah closest to NTS received the highest exposures, but noted that residents of urban northern areas received a higher mean dose and a significantly greater population dose than did residents of most counties closer to the test site. Northern Utah residents received higher average bone doses than southern Utah residents; therefore, the distance from NTS should not be the sole criteria for dividing the State into geographic subgroups for the purpose of conducting epidemiologic studies. Beck and Krey concluded that bone doses to southern Utah residents were too low to account for the excess leukemia deaths identified by Lyon et al. They also determined that bone and whole body doses from NTS fallout were small relative to lifetime doses most Utah residents receive from background radiation, and that it was unlikely that these exposures would have resulted in any observed health effects.

Land et al. attempted to confirm the association between leukemia and fallout reported by Lyon et al. using cancer mortality data from the National Center for Health Statistics for the period 1950 through 1978 (NEJM 1979a:397-402); (Science 1984a:139-144). No statistically significant differences in mortality from leukemia or other childhood malignancies between northern (SRR=1.52, 90 percent CI=1.24-1.87) and southern Utah (SRR=1.49, 90 percent CI=0.88-2.51) were observed. The observed difference in leukemia mortality between the border and interior counties was opposite in direction to that reported by Lyon et al. Results indicated a downward trend in childhood leukemia mortality over time. Eastern Oregon and the State of Iowa also were selected for comparison with Utah. The leukemia mortality rate for eastern Oregon was higher (SRR=1.81, 90 percent CI=1.07-3.07), and Iowa lower (SRR=1.16, 90 percent CI=1.02-1.31) than the rate for Utah (SRR=1.49, 90 percent CI=0.88-2.51. Land et al. concluded that these results suggest that the association reported by Lyon et al. merely reflects an unexplained low leukemia rate in southern Utah for the period 1944 to 1949.

Another study that assessed the development of cancer among individuals potentially exposed to radioactive fallout has been reported by Rallison et al. (HP 1990c:739-746). This study examined the thyroid neoplasia risk in a cohort of children born between 1947 and 1954 in two counties near nuclear test sites, one in Utah and one in Nevada. A comparison group of Arizona children presumed to have no fallout exposure was also evaluated. The children (11 to 18 years of age) were examined between 1965 and 1968 for thyroid abnormalities and were reexamined in 1985 and 1986. Children living in the nuclear testing (Utah/Nevada) area had a higher rate of thyroid neoplasia (5.6/1000 for phase 1 and 24.6/1000 for phase 2) than the comparison children in Arizona (3.3/1000 for phase and 20.2/1000 for phase 2), but the differences were not statistically significant (RR=1.2, p=0.65 for phase 2). The authors concluded that living near the NTS in the 1950s has not resulted in a statistically significant increase in thyroid neoplasms.

A study by Johnson examined cancer incidence in a cohort of families that were members of the Church of Jesus Christ of Latter-Day Saints in southwest Utah near the NTS (JAMA 1984b:230-236). The study compared cancer incidence among all Utah members of the Church of Jesus Christ of Latter-Day Saints during the period 1967-1975 with cancer incidence among two exposed populations: persons residing in a "high fallout area"' and an "exposure effects group" residing in a broader area that received less intense exposure from radioactive fallout. Limitations of the study include: the inability to locate 40 percent of the defined population; the lack of verifying the reported diagnosis of cancer; and the inability to interview a comparable control group.

Cancer incidence for both exposed groups was compared with that of all Utah members of the Church of Jesus Christ of Latter-Day Saints for two time periods, 1958-1966 and 1972-1980. Johnson found an apparent increased incidence of leukemia (19 cases, 3.6 expected, p=0.01) and cancers of the thyroid (6 observed, 1.4 expected, p=0.01) and bone (3 observed, 0.3 expected, p=0.01) for residents of the high fallout area for both time periods. Additional analyses suggested that a higher proportion of the cancers among exposed groups were in radiosensitive tissues and the proportional excess increased with time compared with all Utah members of the Church of Jesus Christ of Latter-Day Saints. The ratio of radiosensitive cancers to all other cancers from 1959-1966 was 24 percent higher among the "high fallout area" group and 29.6 percent higher among those in the "fallout effects" group. For 1972-1980, the ratio was 53.3 percent higher in the "high fallout area" group and 300 percent higher in the "fallout effects" group.

Machado examined cancer mortality rates of a three-county region in southwestern Utah in comparison to the remainder of Utah (AJE 1987c:44-61). There was no excess risk of cancer mortality in southwest Utah, with the exception of leukemia (OR=1.45, 90 percent CI=1.18-1.79 with Utah controls), which showed a statistically significant excess for all ages combined, and for children age 0-14. In fact, mortality from all cancer sites combined was lower in southwest Utah than the remainder of the State. The authors noted that their findings, including those for leukemia, were inconsistent with the cancer incidence study conducted by Johnson (JAMA 1984b:230-236).

Archer measured soil, milk, and bone strontium-90 levels to identify states with high-, intermediate and low-fallout contamination (AEH 1987a:263-271). He then correlated the deaths from radiogenic and nonradioactive leukemias with the time periods of above ground nuclear testing both in the United States and Asia. The results show that leukemia deaths in children were higher in States with high exposure and lower in States with less exposure. He showed that leukemia deaths in children peaked approximately 5.5 years following nuclear testing peaks. The last leukemia peak in the United States occurred in 1968 to 1969, 5.5 years after the last year of a 3-year period of intensive testing in Asia. The increases were seen in the radiogenic leukemias (myeloid and acute leukemias), and not with "all other leukemias."

Kerber et al. updated a previously identified cohort of children living in portions of Utah, Nevada, and Arizona, to estimate individual radiation doses and determine thyroid disease status through 1985-1986 (JAMA 1993a:2076-2082). Of the 4,818 children originally examined between 1965-1970, 2,473 were included in the followup exam. Outcomes of interest included thyroid cancers, neoplasms, and nodules based on physical examinations of the thyroid. Exposure of the thyroid to radioiodines was based on radionuclide deposition rates provided by DOE and surveys of milk producers. Children with questionable findings were referred to a panel of endocrinologists for further examination. The authors reported an excess number of thyroid neoplasms (combined benign and malignant) and a positive dose-response trend for neoplasms, both of which were statistically significant. The authors also reported a positive dose-response trend for thyroid nodules, not statistically significant, and a positive dose-response trend for thyroid carcinomas with marginal statistical significance. The authors estimated that an excess of between 1 and 12 neoplasms (between 0 to 6 excess malignancies was probably caused by exposure to radioiodines from the nuclear weapons testing. A letter to the editor criticized Kerber et al. for relying on food histories obtained 22 years after the fact to depict radioiodine intake, and for the untested modeling approach-for determining dose to the thyroid (JAMA 1994a:825-826). These concerns were addressed by Kerber et al., which acknowledged the uncertainties in the dose estimates, but concluded that their estimates were conservative (JAMA 1994a:826).

Till et al. estimated doses to the thyroid of 3,545 subjects who were exposed to radioiodine fallout from NTS (HP 1995a:472-483). The U.S. Public Health Service first examined this cohort for thyroid disease between 1965-70 and later in 1985-86. Till et al. assigned individual doses based on age, residence histories, dietary histories, and lifestyle. Individualized dose and uncertainty was combined with the results of clinical examinations to determine the relationship between dose from NTS fallout and thyroid disease incidence.

Workers. Military personnel and civilian employees of the Department of Defense observed and participated in maneuvers at the NTS Test Range Complex during above ground tests. An excess number of leukemia cases was reported (9 cases, 3.5 expected) among the 3,224 men who participated in military maneuvers in August 1957 at the time of the nuclear test explosion "Smoky" (JAMA 1980a:1575-1578). The participants were located and queried on their health status, diseases, or hospitalizations as of December 1981. Various Federal records systems were linked, including clinical files, and next of kin was queried about cause of death for those participants who were deceased. Exposure information was available from film badged records, and the mean gamma dose for the entire cohort was 466.2 mrem. In a later report of the same cohort, the number of incident cases of leukemia had increased to 10 with 4 expected (O/E=2.5, 95 percent CI=1.2-4.6) (JAMA 1983a:620-624). No excess in "total cancers" was observed, however. In addition, four cases of polycythemia vera were reported where 0.2 was expected (JAMA 1984a:662-664). The excess in leukemia cancer incidence and mortality appear to be limited to the soldiers who participated in "Smoky."

The leukemia excess was not observed in a National Research Council mortality study of soldiers exposed to five series of tests at two sites: Nevada Test Site (PLUMBBOB) and the Pacific Proving Ground (DOE 1985b). The National Research Council reported that the number of leukemia cases in "Smoky" was greater, but the increase was considered nonsignificant when analyzed with the data from the other four tests. In 1989, however, it was discovered that the roster of the atomic veterans cohort on which the National Research Council based its 1985 study contained misclassification errors. As a result, this study is being reanalyzed, and the National Research Council anticipates publishing the new results by 1997.

M.4.4 IDAHO NATIONAL ENGINEERING LABORATORY

Surrounding Communities

Jablon et al. examined cancer mortality in populations living near nuclear facilities in the U.S., including INEL in Idaho (JAMA 1991a:1403-1408). The study compared cancer mortality from 1950-1984 in 107 counties with or near 62 nuclear facilities with cancer mortality in control counties without nuclear facilities. Cancer mortality for Bingham, Butte, and Jefferson Counties, where INEL is located, was compared with nine control counties in the same region, with similar demographic characteristics. The authors concluded that no general association was detected between residents in a county with a nuclear facility and death attributable to leukemia or any other form of cancer. The authors noted that interpretation of the study results is limited by the study's ecological approach in which the exposures of individuals are not known.

Cancer morbidity and mortality data in two additional counties near INEL, Clark and Minidoka, were reviewed by the Idaho Department of Health and Welfare (ID DHW 1991a; ID DHW 1991b). Clark County lies northeast of INEL and Minidoka County southwest of INEL. Cancer death rates were examined for the years 1950-1989 and cancer incidence rates for the years 1978-1987 to determine if any significant trends in cancer morbidity and mortality could be observed in these counties compared with the entire State. No statistically significant differences in age- and sex-adjusted death rates were observed in either county.

When cancer incidence data were considered, the overall cancer incidence rate in Clark County was higher than expected based on the State of Idaho's experience. When the Clark County data were examined by primary site, only two sites were found to be significantly higher than expected—female breast cancer (8 cases observed vs. 3.2 expected, p=0.05) and lip cancer (3 cases observed vs. 0.4 expected, p=0.05). In Minidoka County, there was no increase in overall cancer incidence rate compared with the entire State. Examination by primary sites in Minidoka County, however, showed three cancer sites were found to be increased—cancer of the stomach (20 cases observed vs. 11.6 expected, p=0.05), lip (23 cases observed vs. 8 expected, p=0.01), and uterus (40 cases observed vs. 24.2 expected, p=0.01). These studies also suffered from the limitations inherent in ecological studies. In addition, the authors noted that too many comparisons were made for "significant" results and that the data for Clark County, with an estimated population of 800, were too small to make meaningful analyses.

State Health Agreement Program

In 1991, INEL completed a historical dose reconstruction study to examine the impact of radioactive materials released to the environment during INEL's past operations. Subsequently, under the State Health Agreement program managed by the DOE Office of Epidemiologic Studies, a grant was awarded to the State of Idaho to convene an expert panel to review the final dose reconstruction report. The State panel evaluated the environmental transport and dose assessment models used for the dose reconstruction and recommended that additional work, involving public participation, be done to more fully examine offsite consequences (ID DHW 1993a).

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Workers

No occupational epidemiologic studies have been completed at INEL to date.

Memorandum of Understanding

DOE entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites, and the Centers for Disease Control and Prevention became responsible for conducting dose reconstructions in several host States, including Idaho. Under the Memorandum of Understanding, Centers for Disease Control began a phased approach to determine the need for an expansion of the dose reconstruction work initiated earlier and reviewed by the State of Idaho. The first part, data identification retrieval, was completed in 1995. No decision about the need for additional phases of a dose reconstruction for INEL has yet been reached. NIOSH is responsible for worker studies and is currently conducting a cohort mortality study of the workforce with a projected completion date of September 1997 (IN DOE 1995e).

Epidemiologic Studies

DOE's Office of Epidemiologic Studies has implemented an epidemiologic surveillance program at INEL to monitor the health of current workers. This program will evaluate the occurrence of illness and injury in the workforce on a continuing basis and the results will be issued in annual reports. The implementation of this program will facilitate an ongoing assessment of the health and safety of INEL's workforce and will help identify emerging health issues.

Currently operational at a number of DOE sites, including production sites and R&D facilities, epidemiologic surveillance uses routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and OSHA recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data for an extended period of time become available, time trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring the health of the workforce provides a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate the need for more detailed study or increased health and safety measures to ensure adequate protection for workers.

M.4.5 PANTEX PLANT

Surrounding Communities. A June 1994 study by the Texas Cancer Registry, Texas Department of Health, showed significant increases in prostate cancer mortality among Potter County and Randall County males, and leukemia mortality among Carson County males during the period 1981-1992 (TX DOH 1994a). There were no statistically significant increases observed in site-specific cancer mortality among females during this period. For cancer incidence during the period 1986-1992, no statistically significant excesses in males were seen; however, cancer of the prostate was slightly elevated in Potter/Randall County males. Analysis of the four major cell-specific types of leukemia, showed a significant excess in the incidence of chronic lymphocytic leukemia among Potter/Randall County females. This study was conducted in Carson, Potter, and Randall Counties, which are located near Pantex. This study focused only on cancers of the breast, prostate, brain, thyroid, and leukemia, which were of specific concern to citizens in the area. Other radiation-associated cancers such as bone and lung, were not included in this study. Although prostate cancer and chronic lymphocytic leukemia have not been linked to radiation exposure, further follow-up to this study was recommended.

Workers. An epidemiologic study of Pantex workers was published by Acquavella (HP 1985a:735-746). This study compared total and cause-specific mortality for Pantex workers employed between 1951 and December 31, 1978, with expected cause-specific mortalities based on U.S. death rates. Significantly fewer deaths were observed in the workforce than would be expected based on U.S. death rates for the following causes of death: all cancers (SMR=0.72; 95 percent CI=0.64 0.81),arteriosclerotic heart disease (SMR=0.75; 95 percent CI=0.61-0.91), and digestive diseases (SMR=0.46; 95 percent CI=0.22-0.85). No specific causes of death occurred significantly more frequently than expected. Slightly elevated mortality ratios were observed for brain cancer (SMR=1.36; 95 percent CI=0.37-3.47) and leukemia (SMR=1.28; 95 percent CI=0.35-3.27); neither excess was statistically significant. The four deaths from brain cancer all occurred among those who had worked at the plant less than 5 years. The four deaths from leukemia occurred with equal frequency among those who had worked at the plant a short time and those who had worked more than 15 years.

Memorandum of Understanding. A follow-up of the 1985 mortality study of the Pantex workforce is planned. The update will be conducted by NIOSH as part of a research program funded by DOE under a Memorandum of Understanding with the Department of Health and Human Services. The followup study is scheduled to commence either in late 1996 or early 1997. In addition, female workers at Pantex will be included in a NIOSH funded multisite study of mortality among female nuclear weapons workers.

Epidemiologic Surveillance. DOE's Office of Epidemiologic Studies' Epidemiologic Surveillance Program was implemented at Pantex in 1993 in order to monitor the health of current workers. This program evaluates the occurrence of illness and injury in the workforce on a continuing basis and issues the results of the ongoing surveillance in annual reports. The program facilitates an ongoing assessment of the health and safety of the site's workforce and helps to identify any emerging health issues in a timely manner. Monthly data collection began on January 1, 1994, and the results of the first complete year of epidemiologic surveillance will be presented to workers and other site stakeholder groups in spring 1996.

Currently operational at a number of DOE sites, including production sites and R&D laboratories, epidemiologic surveillance makes use of routinely collected health data including descriptions of illness resulting in absences lasting five or more consecutive workdays, disabilities, and OSHA recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data become available for an extended period of time, trend analysis will become an increasingly important part of the evaluation of workers health. Monitoring for changes in the health of the work force provides both a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate areas in need of more detailed study or increased health and safety measures to ensure adequate protection for workers.

M.4.6 OAK RIDGE RESERVATION

Surrounding Communities. The population-based National Cancer Institute mortality survey for selected nuclear facilities (NIH Publication No. 90-874; JAMA 1991a:1403–1408) examined the cancer mortality in communities near several nuclear facilities, including Anderson and Roane counties. No excess cancer mortality was observed in the population living in the exposed counties when compared to the U.S. white male population nor when compared to the population of the control counties (Blount, Bradley, Coffee, Jefferson, Hamblen, TN, and Henderson, NC), nor when time trends were assessed.

Tennessee Medical Management, Inc. used data from the Tennessee Cancer Reporting System to compare mortality and incidence data for counties near Oak Ridge, Tennessee, for the 3-year period 1988-1990 to the U.S. population (TMM 1993a). For Oak Ridge, total deaths from all causes was significantly lower than expected. For Anderson County, the observed number of deaths from uterine cancer and from cancer of

respiratory and intrathoracic organs was statistically greater than expected and the number of deaths from brain cancer, breast cancer, and all the other sites category were lower than expected for Anderson County. For Roane County, the number of deaths from cancer of the respiratory and intrathoracic organs was statistically greater than expected; the number of deaths from cancer of the digestive organs and the peritoneum, and from uterine, lip, oral cavity, and pharynx cancer was lower than expected.

Tennessee Medical Management, Inc. examined new (incident) cancer cases and identified the following statistically significant: for Anderson County, the observed numbers of cases of cancer of the prostate and of cancer of the lung and bronchus were greater than expected. Leukemia, stomach and small intestine cancers, and cancers of the colon and intestinal tract were lower than expected. For Roane County, the number of cases of cancer of the lung and bronchus was greater than expected. Non-Hodgkin's lymphoma, female breast cancer, esophageal cancer, cancer of the pancreas, and cancer in all sites were lower than expected. The only consistent excess reported for both cancer mortality and cancer incidence was for cancer of respiratory and intrathoracic organs.

Because of a concern for possible contamination of the population by mercury, the Tennessee Department of Health and Environment conducted a pilot study in 1984 (TN DHE 1984a). The study showed no difference in urine or hair mercury exposures (residence or activity in contaminated areas) compared to those with little potential exposure. Mercury levels in some soils measured as high as 2,000 parts per million. Analysis of a few soil samples showed that most of the mercury in the soil however, was inorganic, thereby lowering the probability of bioaccumulation and health effects. Examination of the long-term effects of exposure to mercury and other chemicals continues.

State Health Agreement Program. Under the State Health Agreement program managed by the DOE's Office of Epidemiologic Studies, a grant was awarded to the Tennessee Department of Health and Environment. The purpose of the grant was to determine the extent of exposure to contaminants among workers and residents of the surrounding community as a result of ORR operations and to assess the current status of health outcomes and determine their potential association with these exposures.

A dose reconstruction feasibility study began in 1992 with the contract awarded by the State of Tennessee to Chemrisk. The contractor performed extensive review of Oak Ridge documents and issued a report which concluded that sufficient information exists to reconstruct past releases and offsite doses caused by radioactive and hazardous materials. The report also concluded that doses from mercury, polychlorinated biphenyls, radioactive iodine, and radioactive cesium may have been great enough to cause harmful health effects in offsite population. Based on this information, a full dose reconstruction study was initiated in August 1994.

Other activities supported under the grant include: development of a birth defects registry; a quality improvement program for the Tennessee cancer registry; a review and evaluation of the DOE occupational medical program; and the implementation of a community participation/public information program.

Technical support to the State health department is provided by a 12 member Oak Ridge Health Agreement Steering Panel. The Health Advisory Panel provides direction and oversight to those working on health studies, ensures public input, and informs the public of activities related to the health studies. A representative of the Centers for Disease Control and Prevention's National Center for Environmental Health is a member of the advisory panel. A representative from DOE serves as an "ex-officio" member.

Workers. Between 1943 and 1985, there were 118,588 male and female individuals of all races who were ever employed in any of the Oak Ridge facilities. These included ORNL for nuclear research (also called the X-10 Facility), Y–12 under management of the Tennessee-Eastman Corporation (1943 to 1947) which produced enriched uranium by the electromagnetic separation process, Y–12 under management of Union Carbide (1948 to 1984) which fabricated and certified nuclear weapons parts, and K–25 (Oak Ridge Gaseous Diffusion Plant) which produced enriched uranium through the gaseous process. Analyses at the Oak Ridge facilities have been

carried out mostly for white males, and for specific cohorts talking into consideration time-related exposure risks.

Oak Ridge National Laboratory. The mortality experience of 8,375 white males employed at least a month between 1943 and 1972 at ORNL was compared with the U.S. white male population using SMR analyses in a 1985 paper by Checkoway, et al. (BJIM 1985a:525-533). Increases in deaths from leukemia (SMR=1.49, .16 observed; 95 percent Confidence Interval=0.31-4.38), cancer of the prostate (SMR=1.16, 14 observed, 11.9 expected), and Hodgkin's disease (SMR=1.10, 5 observed, 3.7 expected) were observed, although none were statistically significant. Dose response analyses were performed for all causes of death combined, all cancers combined, leukemia, and prostate cancer comparing exposed worker death rates with non-exposed worker death rates. Dosimetry data were available for the entire period of the study with the total population external radiation dose measuring 135 Sv. No dose response gradients were observed. Death rates were calculated for 11 different job categories by length of time in each job in an attempt to determine whether specific work environments were related to cancer and leukemia. Leukemia mortality was observed to be related to length of employment in engineering and maintenance jobs.

Follow-up of this cohort was extended through 1984 in an updated study by Wing et al. (JAMA 1991a:1397-1402). Again, death rates in the worker population were compared with those in the U.S. population. Non-statistically significant increases were noted for cancers of the pancreas (SMR=1.09, 25 observed, 95 percent CI=0.71-1.61), prostate (SMR=1.05, 26 observed, 95 percent CI=0.68-1.53), brain (SMR=1.04, 15 observed, 95 percent CI=0.58-1.72), and lymphosarcoma and/or reticulosarcoma (SMR=1.05, 9 observed, 95 percent CI=0.48-1.99). There was a significant increase in deaths from leukemia (SMR=1.63, 28 observed, 95 percent confidence, interval 1.08-2.35). The total population external radiation dose was 144 Sv. Dose response analyses performed for all causes except cancer, lung cancer, and leukemia did not demonstrate a relationship between level of external radiation and increased risk of death from these outcomes. There was a significant dose response relationship (4.94 percent per 10 milliSieverts) between cancer deaths and level of external radiation dose using models with a 20-year lag. A subgroup of workers who were monitored for internal contamination had non-statistically elevated SMRs for cancer of the prostate (SMR=1.12 10-observed), 95 percent CI=0.53-2.05 and lymphosarcoma and/or reticulosarcoma (SMR=1.65, 6 observed, 95 percent CI=0.60-3.59). The workers monitored for internal contamination had a statistically significant elevated SMR for leukemia (SMR=2.23, 16 observed, 95 percent CI=1.27-3.62).

A second publication on the above data set (Wing, et al), examined the effect of controlling for a number of possible selection and confounding factors on the risk coefficient for all cancer dose responses (AJIM 1993a:265-279). Models were adjusted for the following variables with little change in the previously reported risk coefficient: employment during the World War II era, short-term employment job category, and exposure to beryllium lead, and mercury. The authors concluded that the previously calculated dose response estimate was fairly stable when adjustments were made for a wide range of potential confounders that were not explored in the earlier study.

Y–12 Plant. Y–12 is a nuclear weapons metals fabrication plant where the radiologic exposure of greatest concern is internal exposure from the inhalation of uranium compounds. The Tennessee Eastman Corporation managed the plant from 1943 to 1947. Polednak and Frome reported a follow-up through 1974 of all 18,869 white male workers employed at Y–12 from 1943 to 1947 (JOM 1981a:169-178). The workers included those exposed to internal ("alpha") and external ("beta") radiation through the inhalation of uranium dusts, electrical workers who performed maintenance in the exposed areas, and other non-exposed workers. Individual measures of exposure were not available for any members of this cohort so exposure levels were inferred from plant areas of work and jobs. High average air levels of uranium dust were documented in departments employing chemical workers. Elevated SMRs were observed for mental, psychoneurotic, personality disorders (SMR=1.36, 33 observed, 24.2 expected), emphysema (SMR 1.16, 100 observed, 85.9 expected), diseases of the bones and organs of movement (SMR=1.22, 11 observed, 8.5 expected), lung cancer (SMR=1.09, 324 observed, 296.5 expected), and external causes of death (SMR=1.09, 623 observed, 571.8 expected). The lung cancer SMR was

greater among workers employed for 1 year or more compared with workers employed less than 1 year and was more pronounced in workers hired at the age of 45 or older (SMR=1.51;95 percent CI 1.01-2.31). Of the workers employed after the age of 44, the SMR for lung cancer was greatest for electrical workers (SMR=1.55, 7 observed, D=1.11), alpha chemistry workers (SMR=3.02, 7 observed, D=2.27) and beta process workers (SMR=1.5, 11 observed, D=1.3).

During the early operation of Y–12, from 1942-1947, a group of male workers was exposed to phosgene gas on a chronic basis (N=694) and a smaller group of males received acute exposures (N=106) along with a small group of females (N=91) (ER 1980a:357-367; TIH 1985a:137-147). A control group of 9,280 workers who also worked at Y–12 during the same era, but who did not have phosgene exposure, was also described. All groups were followed through the end of 1978. The SMRs for the chronically-exposed group and the control group, were similar for all causes examined. There was no evidence for increased mortality from respiratory diseases in this group and the SMR for lung cancer, while elevated, was similar to the lung cancer SMR for workers in the rest of the plant. Among those with acute exposures, the SMR for respiratory diseases was elevated (SMR=2.66, 5 observed). This elevation may be related to residual lung damage from the acute phosgene exposure. It was difficult to trace the vital status of the 91 women; therefore, description of these highly exposed workers was limited to listing the frequency of their initial symptoms after exposure. As expected, nausea, vomiting and cough were the most frequently reported symptoms. Unexpectedly, the women experienced a lower frequency of pneumonitis than their male counterparts.

The portion of the Y–12 cohort employed between 1947 and 1974 was described by Checkoway et al. (AJE 1988a:255-266). This study included 6,781 white male workers first employed at Y–12 between 1947 and 1974 who were employed for at least 30 days. Mortality data were collected for the cohort through the end of 1979 and were used to perform SMR and cause specific dose-response analyses. Non-statistically significant increases were observed for all cancers (SMR=1.01, 196 observed, 95 percent CI=0.88-1.17), diseases of the blood-forming organs (SMR=1.48, 3 observed, 95 percent CI=0.31-4.38), kidney cancer (SMR=I.22, 6 observed, 95 percent CI=0.45-2.66), brain cancer (SMR=1.80, 14 observed, 95 percent CI=0.98 - 3.02), and other lymphatic cancers (SMR=1.86, 9 observed, 95 percent CI=0.85-3.53). A statistically significant increase in deaths from lung cancer (SMR=1.36, 89 observed; 95 percent CI=1.09-1.67) was observed compared with the U.S. lung cancer rates, but not with Tennessee lung cancer rates (SMR=1.18, 95 percent CI=0.95-1.45). Dose-response analyses for lung cancer and internal alpha radiation dose and external gamma radiation dose did not reveal a positive relationship for a 0-year or 10-year lag. Examination of lung cancer rates distributed across both internal and external dose categories suggested a dose-response with external radiation dose among individuals who had 5 or more rems of internal dose. Brain cancer was not related to the level of internal or external radiation dose.

The Y–12 cohort studied by Checkoway was updated through the end of 1990 by Loomis and Wolf and included African-American and white female workers (AJIM 1996a:131-141). The dose-response analyses were not included in the update; therefore, only SMR analyses are reported. For all workers examined as a group, non-statistically significant elevations were observed for cancer of the pancreas (SMR=1.36, 34 observed, 95 percent CI=0.94-1.90), skin cancer (SMR)=1.07, 11 observed, 95 percent CI=0.54-1.92), breast cancer (females only, SMR=1.21, 11 observed, 95 percent CI=0.60-2.17), prostate cancer (SMR)=1.31, 36 observed, 95 percent CI=0.91-1.81), kidney cancer (SMR=1.30, 16 observed, 95 percent CI=0.74-2.11), brain cancer (SMR=1.29, 20 observed 95 percent CI=0.79-2.00), cancers of other lymphatic tissues (SMR=1.32, 22 observed, 95 percent CI=0.82-1.99) and diseases of the blood forming organs (SMR=1.23, 6 observed, 95 percent CI=0.45-2.68). The SMR for lung cancer was statistically significant (SMR=1.17, 202 observed; 95 percent CI 1.01-1.34), particularly in the white male segment of the population (SMR=1.20, 194 observed 95 percent CI=1.04-1.38). Examination of the lung cancer mortality by year of hire, latency, duration of employment and calendar year at risk indicated the excess was confined to those who were first hired before 1954 (SMR=1.27, 161 observed), and was greatest in persons employed 5 to 20 years with 10 to 30 years of follow-up. Elevated lung cancer deaths rates were first evident between 1955 and 1964 and continued to increase from 1975 to 1979, followed by a decrease in lung cancer death rates.

Between 1953 and 1963, Y–12 used mercury in a process to produce large quantities of enriched lithium. Cragle et al. studied all workers employed at Y–12 at least 5 months between January 1, 1953 and April 30, 1958 (N=5,663) (JOM 1984a:817-821). This group was categorized into workers exposed to mercury and workers not exposed to mercury based on results of urinalysis data supplied by the plant. Vital status follow-up was complete through the end of 1978, and SMRs were calculated. Compared with non-exposed workers, there were no differences in the mortality patterns for mercury exposed workers as a whole, workers with the highest mercury exposures, and workers employed more than a year in a mercury process. The authors acknowledge that mortality is not the optimal end point to assess health effects related to mercury exposure.

The mercury workers were involved in a clinical study by Albers et al. who examined 502 Y–12 workers, 247 of whom worked in the mercury process 20 to 35 years prior to the examination (AN 1988a:651-659). Correlations between declining neurological function and increasing exposure were identified. An exposure assessment was determined for each mercury worker during the time of employment in the mercury process. Study subjects who had at least one urinalysis equal or greater than 0.6 mg./L of mercury showed decreased strength, coordination and sensations along with increased tremor, and prevalence of Babinski and snout reflexes when compared with the 255 unexposed workers. Clinical polyneuropathy was associated with the level, of the highest exposure, but not with the duration of exposure.

K–25 Site. The K–25 Site enriched uranium beginning in 1945 using a gaseous diffusion process. There was potential exposure to uranium dust, oxidized uranium compounds, uranium hexafluoride, and a number of chemical compounds used in the process. In later years of operation, the gas centrifuge process was used to enrich uranium. No analyses of death rates for this population have been published; however, health effects have been studied.

Powdered nickel was used at K–25 in the production of the barrier material used to separate and enrich uranium. Workers who fabricated the barrier material were exposed to nickel powder through inhalation. Cragle et al. updated an earlier study by Godbold et al. of 814 workers who were employed in the manufacture of barrier material between 1948 and 1953 (JOM 1979a:799-806); (IARC 1984a:57-63). A comparison group of white males employed at K–25 sometime between 1948 and 1953 (N=7,552) was also selected. The SMRs in the barrier group were similar to those in the non-barrier worker group for most non-cancer outcomes. The nickel workers were noted to have a higher rate of death from cancers of the buccal cavity and pharynx (SMR=2.92, 3 observed, 95 percent CI=0.59-8.54) than the non-nickel workers (SMR=0.23, 3 observed, 95 percent CI=0.05-0.67). When the standardized rates were directly compared, the rate of buccal cavity and pharynx cancer in the nickel workers was approximately 19 times higher than the rate in the non-nickel workers. The authors acknowledge that the number of cases is quite small and recommended additional follow-up to determine if this trend continued. There were no nasal sinus cancers observed in the worker population exposed to metallic nickel in contrast to the results of studies of workers in nickel refineries where the rates of sinus cancer related to nickel compounds are quite high.

K–25 workers employed in the gas centrifuge process were the focus of an interview study by Cragle et al. (AOEH 1992a:826-834). The study was conducted in order to determine the incidence rate for cancer and illness symptoms among workers exposed to epoxy resin and solvents prevalent in the process. A total of 263 workers determined to have worked closest and longest to the process were compared with 271 employees employed at the plant during the same time, but did not work in the centrifuge process. The centrifuge workers and the non-centrifuge workers had similar overall cancer incidence rates. However, the centrifuge workers reported five incident bladder cancers versus none reported by the non-centrifuge group. The centrifuge workers also reported significantly more rashes, dizziness, and numb or tingling limbs during employment, which are symptoms associated with high solvent exposure. One of the epoxy resins used in the early years of the process was a potential bladder carcinogen, but none of the workers with bladder cancer had jobs that required routine, hands-on work with that material. A specific causative agent for the increase in bladder cancer was not identified.

Combined-Oak Ridge Reservation Facilities. Frome et al. reported on the mortality experience of World War II workers employed at three ORR facilities between 1943 and 1947 (RR 1990a:138-152). Poisson regression analyses were used to control for potential confounders such as facility of employment, socioeconomic status, period of follow-up, and birth year. The cohort included white males employed at any ORR facility at least 30 days between the start of the operation and 1947 and were never employed at an ORR facility after 1947 (N=28,008). Elevated mortality was statistically significant for all causes (SMR=1.11, 11,671 observed, 10,537 expected; standard deviation (sd)=1), tuberculosis (SMR=1.37, 108 observed, 78 expected; sd=10.2), mental, psychoneurotic, and personality disorders (SMR=1.60, 81 observed, 50 expected; sd=10.2), cerebrovascular disease (SMR 1.11, 833 observed, 753 expected; sd=3.9), diseases of the respiratory system (SMR=1.25, 792 observed, 634 expected; sd=4.4), emphysema (SMR=1.24, 209 observed, 168 expected; sd=8.4), all accidents (SMR=1.28, 694 observed, 542 expected, sd=3.8), and motor vehicle accidents (SMR=1.44, 339 observed, 235 expected; sd=5.5). The only elevated site specific cancer that was statistically significant was lung cancer (SMR=1.27, 850 observed, 667 expected, sd=4.4, $p<0.01$). A surrogate for radiation exposure based on a workers job and department was used to indicate the probability of exposure. This surrogate for actual radiation exposure was not associated with increased rates of cancer.

Carpenter investigated earlier reports of an association between brain cancer and employment at Y–12 by conducting a case-control study of workers employed between 1943 and 1977 at ORNL or Y–12 (JOM 1987a:601-604). Cases consisted of 72 white males and 17 white females with brain cancer. Four controls were selected for each case matched on age, sex, cohort, year of birth, and year of hire. Analyses with respect to internal and external radiation exposures indicated no association with brain cancer. Two companion papers were also published from this case-control study, one examined relationships between brain cancer and chemical exposures, and the other examined non-occupational risk factors (AJIM 1988a:351-362); (AJPH 1987a:1180-1182). No statistically significant association between the use of 26 chemicals evaluated and the risk of brain cancer was observed. The chemicals evaluated included those encountered in welding fumes, beryllium, mercury, 4,4-methylene is 2-chloroaniline or MOCA, cutting oils, thorium, methylene chloride, and other solvents. Excess brain cancer was observed among individuals employed for more than 20 years (odds ratio=7.0, 9 cases; 95 percent CI 1.2-41.1). Analysis of 82 cases with complete medical records revealed an association with a previous diagnosis of epilepsy (odds ratio=5.7, 4 cases; 95 percent. CI=1.0-32.1) recorded for pre-employment and health status follow-up.

Causes of death among white male welders (N=1,059) employed between 1943 and 1973 at Y–12, the K–25 Site, and ORNL were studied by Polednak (AEH 198la:235-242). Based on deaths reported through 1974, mortality from all causes for welders was slightly lower than that expected based on death rates for U.S. white males (SMR=0.87, 173 observed, 199 expected, 95 percent CI=0.75-1.01). Non-statistically significant decreases in mortality were also observed for all cancers (SMR=0.88, 32 observed, 36.57 expected, 95 percent CI=0.60-1.23), especially digestive cancer (SMR=0.49, 5 observed, 10.3 expected, 95 percent CI=0.16-1.14); diseases of the circulatory system (SMR=0.74, 72 observed, 97.51 expected, 95 percent CI=0.58-0.94); diseases of the digestive system (SMR=0.76, 9 observed, 11.86 expected 95 percent, CI=0.35-1.4), and accidents (SMR=0.89, 16 observed, 17.86 expected, 95 percent CI=0.51-1.44). Non-statistically significant increases were noted for lung cancer (SMR=1.50, 17 observed, 11.37 expected, 95 percent CI=0.87-2.40); diseases of the respiratory system (SMR=1.33, 13 observed, 9.77 expected, 95 percent CI=0.71-2.27), especially emphysema (SMR=2.21, 6 observed, 2.71 expected, 95 percent CI=0.81-4.82); and suicide (SMR=1.64, 10 observed, 6.09 expected; 95 percent CI=0.79 - 3.02). A subgroup of welders (N=536) exposed to nickel oxides (possible respiratory carcinogens) at K-25 were compared with welders at the other two facilities (N=523). The risk of lung cancer and other respiratory diseases did not differ between the two groups.

Combined Nuclear Sites. ORR workers have been included in several studies that have examined occupational risks across the nuclear complex, both in the United States and internationally. These combined studies have been undertaken in an attempt to increase the statistical power of the studies to detect the effects of low-level chronic radiation exposure.

Y–12 workers were included in a lung cancer case-control study of workers from the Fernald Feed Materials and Production Center cohort and the Mallinckrodt Chemical Works cohort. Dupree et al. conducted a nested case-control study of lung cancer (N=787) to investigate the relationship between lung cancer and uranium dust exposure (Epidemiology 1995a:370-375). Eligible cases were employed at least 183 days in any of the facilities and died before January 1, 1983, with lung cancer listed anywhere on the death certificate. Inclusion of deaths through 1982 allowed over 30 years of observation at each facility. One control was matched to each case on facility, race, gender, and birth and hire dates within three years. Data collected on all study members included smoking history, first pay code (a surrogate for socioeconomic status), complete work histories and occupational radiation monitoring records. Annual radiation lung dose from deposited uranium was estimated for each study member. Annual external whole body doses from gamma radiation were determined for workers who had personal monitoring data available. Potential confounders considered in the analysis were smoking (ever/never used tobacco) and pay code (monthly/non-monthly). With a 10-year lag, cumulative lung doses ranged from 1 to 137 centigays (cGy) for cases and from 0 to.80 cGy for controls. The odds ratios for lung cancer mortality for seven cumulative internal dose groups did not demonstrate increasing risk with increasing dose. An odds ratio of 2.0 was estimated for those exposed to 25 cGy or more, but the 95 percent confidence interval of 0.20 to 20 showed great uncertainty in the estimate. There was a suggestion of an exposure effect for workers hired at age 45 years or older.

A combined site mortality study included workers from ORNL, the Hanford Site and the Rocky Flats Plant (RR 1993a:408-421). Earlier analyses of these cohorts by Gilbert et al. indicated that risk estimates calculated through extrapolation from high-dose data to low-dose data did not seriously underestimate risks of exposure to low-dose radiation (AJE 1990a:917-927; RR 1989a:19-35). The updated analyses were performed in order to determine whether the extrapolated risks represented an over-estimation of the true risk at low doses. The study population consisted of white males employed at one of the three facilities for at least six months and monitored for external radiation. The Hanford population also included females and non-white workers. The total population dose was 1,237 Sv. Analyses included trend tests for site specific cancer deaths and several broad non-cancer categories. Statistically significant trends were noted for cancer of the esophagus, cancer of the larynx, and Hodgkin's disease. These cancers were not related to radiation exposure levels in previously published studies. Excess relative risk models were calculated for the combined DOE populations and for each DOE site separately. Without exception, all risk estimates included the possibility of zero risk (that is, the confidence interval for the risk coefficient went from below zero to above zero). There was evidence of an increase in the excess relative risk for cancer with increasing age in the Hanford and ORNL population; both populations showed significant correlations of all cancer with radiation dose among those 75 years and older.

An international effort to pool data from populations exposed to external radiation included the ORNL population in addition to other radiation worker populations in the United States, Canada, and Britain (RR 1995a:117-132). The cohort comprised 95,673 workers (85.4 percent men) employed 6 months or longer and the population dose was 3,843.2 Sv. There was no evidence of an association between radiation dose and mortality from all causes or from all cancers. There was a significant dose-response relationship with leukemia, excluding chronic lymphocytic leukemia (excess relative risk=2.18 per SV, 90 percent CI=0.1-5.7) and multiple melanoma (excess relative risk not computed; 44 observed). The study results do not suggest that current radiation risk estimates for cancer at low levels of exposure are appreciable in error.

Memorandum of Understanding. The Department entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites. NIOSH is responsible for the conduct or management of worker studies.

The following studies at the ORR are managed by NIOSH with funding from DOE: a study of multiple myeloma among workers at the K-25 Plant at Oak Ridge (expected completion date 1996); a multisite study to assess the potential association between paternal exposure to ionizing radiation and the risk of leukemia in offspring of exposed male workers; a study of neurologic health outcomes in workers exposed to high levels of mercury between 1953 and 1963; studies of mortality among Oak Ridge workers; a multisite study of mortality

among female nuclear workers; a multi-site exposure assessment of hazardous waste/cleanup workers; a chronic beryllium disease study; and a multi-site study of heat stress and performance among carpenters.

M.4.7 SAVANNAH RIVER SITE

The Savannah River Site, established in 1953 in Aiken, SC, produced Pu, tritium, and other nuclear materials. There are reports that millions of curies of tritium have been released over the years both in plant exhaust plumes and in surface and groundwater streams (ED 1982a:135-152).

Surrounding Communities. In 1984, Sauer and Associates examined mortality rates in Georgia and South Carolina by distance from the Savannah River Plant (now known as the SRS) (SR duPont 1984b). Rates for areas near the plant were compared with U.S. rates and with rates for counties located more than 50 miles away. Breast cancer, respiratory cancer, leukemia, thyroid cancer, bone cancer, malignant melanoma of the skin, non-respiratory cancer, congenital anomalies or birth defects, early infancy death rates, stroke, or cardiovascular disease in the populations living near the plant did not show any excess risk compared with the reference populations.

State Health Agreement Program. Under the State Health Agreement program managed by the DOE Office of Epidemiologic Studies, a grant was awarded to the Medical University of South Carolina in 1991 to develop the Savannah River Region Health Information System. The purpose of the Savannah River Region Health Information System database was to assess the health of populations surrounding SRS by tracking cancer rates and, birth defect rates in the area. Information from the registry is available to public and private health care providers for use in evaluating cancer control efforts. A steering committee provides advice to the Savannah River Region Health Information System and communicates public concerns to Savannah River Region Health Information System. It consists of 12-community members and persons with technical expertise representing South Carolina and Georgia. The meetings are open to the public.

Workers. A descriptive mortality study was conducted that included 9,860 white male workers who had been employed at least 90 days at the Savannah River Plant between 1952 and the end of 1974 (AJIM 1988b:370-401). Vital status was followed through the end of 1980 and mortality was compared with the U.S. population. SMRs were computed separately for hourly and salaried employees. For hourly employees non-statistically significant increases were seen for cancer of the rectum (SMR=1.09, 5 observed, 95 percent CI=0.35-2.54), cancer of the pancreas (SMR=1.08, 10 observed, 95 percent CI=0.59-2.18), leukemia and aleukemia (SMR=1.63, 13 observed, 95 percent CI=0.87-2.80), other lymphatic tissue (SMR=1.06, 5 observed, 95 percent CI=0.34-2.48), benign neoplasms (SMR=1.33, 4 observed, 95 percent CI=0.36-3.40), and motor vehicle accidents (SMR=1.10, 63 observed, 95 percent CI=0.84-1.4). Salaried employees exhibited non-statistically significant increases in cancer of the liver (SMR=1.84, 3 observed, 95 percent CI=0.38-5.38), cancer of the prostate (SMR=1.35, 5 observed, 95 percent CI=0.44-3.16), cancer of the bladder-(SMR=1.87, 4 observed, 95 percent CI=0.51 4.79), brain cancer (SMR=1.06, 4,observed, 95 percent CI=0.29-2.72), leukemia and aleukemia (SMR=1.05, 4 observed, 95 percent CI=0.29-2.69), and other lymphatic tissue (SMR=1.23, 3 observed, 95 percent CI=0.26-3.61). No trends between increasing duration of employment and SMRs were observed. A statistically significant excess of leukemia deaths was observed for hourly workers employed at least 5, but less than 15 years (SMR=2.75, 6 observed, 95 percent CI=1.01-5.99). Review of the plant records and job duties of the workers who died from leukemia indicated that two of the cases had potential routine exposure to solvents, four had potential occasional exposure to solvents and one had potential for minimal exposure. Benzene, a known carcinogen was reportedly not used at the plant.

Epidemiologic Studies. The Department's Office of Epidemiologic Studies has implemented an Epidemiologic Surveillance Program at SRS to monitor the health of current workers. This program will evaluate the occurrence of illness and injury in the workforce on a continuing basis and the results will be issued in annual reports. The implementation of this program will facilitate an ongoing assessment of the health and safety of SRS's workforce and will help identify emerging health issues.

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Currently operational at a number of DOE sites, including production sites and R&D facilities, epidemiologic surveillance uses routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and OSHA recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data for an extended period of time become available, time trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring the health of the workforce provides a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate the need for more detailed study or increased health and safety measures to ensure adequate protection for workers.

Memorandum of Understanding. The Department entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites. The Centers for Disease Control and Prevention's National Center for Environmental Health is responsible for dose reconstruction studies and NIOSH is responsible for worker studies. These activities are funded by DOE.

A study of mortality among SRS workers employed from 1952 to 1974 to examine whether risks of death due to selected causes may be related to occupational exposures at SRS is being conducted by NIOSH. SRS is also included in several multisite studies managed by NIOSH. The first study is to assess the potential association between paternal work-related exposure to ionizing radiation and the risk of leukemia in offspring of exposed male workers. The second study is to examine causes of death among female workers at nuclear weapons facilities to develop risk estimates based on exposures to external and internal ionizing radiation and to hazardous chemicals. A third multi-site project is a case-control study of multiple myeloma; a type of blood cell cancer.

A dose reconstruction project around SRS is being conducted by the National Center for Environmental Health to determine the type and amount of contaminants to which people living around the site may have been exposed, to identify exposure pathways of concern and to quantify the doses people may have received as a result of SRS operations. The estimated completion date is 1999 or 2000.

M.4.8 ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

Surrounding Communities

Johnson examined cancer incidence from 1969 to 1971 among non-Hispanic whites in the Denver area to determine if exposure to a small concentration of Pu and other radionuclides had increased the incidence of cancer (Ambio 1981a:176-182). The authors categorized census tracts into four areas based on Pu isotope concentrations in soil from a 1970 Atomic Energy Commission survey. The highest concentrations of Pu were closest to the Rocky Flats Plant (Area I) and decreased with distance from the plant (Areas II & III). Area IV was considered unexposed. The study calculated cancer incidence rates for each of the four areas. To account for confounding factors, median income and education levels of the study and control populations derived from 1970 census data also were considered.

Cancer incidence appeared to be inversely proportional to the distance from Rocky Flats. Among males, total cancer incidence for 1969-1971 was significantly elevated by 24 percent in Area I and by 15 percent in Area II compared with Area IV. Among women, total cancer incidence was 10 percent higher in Area I than Area IV. When specific cancer sites for each area were compared with Area IV, cancer of the lung and bronchus was significantly elevated in men by 33 percent in Area I and by 46 percent in Area II. Cancers of the colon and rectum were significantly elevated in men by 47 percent and in women by 37 percent in Area I. Leukemia was significantly elevated in women in Area III by 58 percent. There were 18 percent fewer leukemia cases than expected among women in Area I. Cancer of the tongue, pharynx, and esophagus was significantly elevated in

men by 139 percent and in women by 257 percent in Area II. Men in Area II also had significant elevations in liver, gallbladder, and testicular cancers. The author concluded that over the study period, cancer incidence increased with increasing Pu soil concentrations and that exposure of the public to low concentrations of Pu and other radionuclides may effect the incidence of total and radiation-related cancer.

To further investigate these reported geographic correlations between Rocky Flats and cancer incidence patterns, Crump et al. re-examined cancer incidence data for the 3-year period studied by Johnson, 1969 to 1971, and also analyzed data from a later period, 1979-1981 (AJE 1987b:127-135). Crump et al. used the same concentration contours for soil Pu contamination as the Johnson study and computed gender- and age-specific cancer rates for each of the four exposure areas. As in the previous study, Area I, with the highest exposure, was closest to Rocky Flats; Area IV was most distant.

The authors' findings paralleled the earlier results of Johnson for 1969-1971. For 1979-1981, significant positive trends were observed in males for total cancer, "radiosensitive cancer," as defined by BEIR III, and respiratory cancer; and in females for total cancer, radiosensitive cancer, and digestive cancer. Whereas cancer incidence tended to decrease with increasing distance from the Rocky Flats Plant for the 1969-1971 study period, cancer incidence in the 1979-1981 time period was lower in Area I, closer to Rocky Flats, than for Area II in six of the cancer sites studied.

To examine the possible effects of urbanization on cancer incidence, census tracts were then grouped by distance from the State Capitol Building. Total cancer incidence was higher nearer to downtown Denver and the State Capitol for males in the earlier period, and for both sexes in the later period. Cancer incidence rates were found to decrease in all directions as one moved away from the State Capitol, including the direction of Rocky Flats. After controlling for distance from the Capitol, the statistically significant association of increases in various cancers among those living near Rocky Flats disappeared.

The authors then compared that part of Area I closest to Rocky Flats (within 16 km) to the whole Denver metropolitan area. No excess was seen for either males or females during either study period for total cancer, radiosensitive cancer, or respiratory cancer.

Crump et al. concluded that this study did not support a correlation between environmental exposure to Pu from Rocky Flats and cancer incidence; correlations of cancer incidence with proximity to Rocky Flats disappeared for both time periods when analyses took into account the levels of urbanization.

Jablon et al. analyzed cause, gender, race, and age-specific cancer mortality from 1950 through 1984 in residents who lived near 62 nuclear facilities throughout the United States (JAMA 1991a:1403-1408). Each of 107 counties with or near nuclear installations, including Jefferson County, where Rocky Flats is located, was matched to three control counties in the same region, without nuclear facilities. The matching criteria included population size, age, race, urban/rural differences, manufacturing, education, income, migration, and infant death rates. The authors concluded that the survey did not detect any general association between residence in a county with a nuclear facility and death attributable to leukemia or any other form of cancer. The authors noted that interpretation of the study results is limited by its ecologic approach in which the exposures of individuals are not known.

State Health Agreement Program

Under the State Health Agreement program managed by the DOE Office of Epidemiologic Studies, a grant was awarded to the Colorado Department of Public Health and Environment for the performance of an offsite historical dose reconstruction. Due to be completed by 1998, this study includes a thorough examination of major fires and other events releasing Pu from Rocky Flats, estimates of resulting risks due to exposure to Pu and other environmental releases, as well as extensive support of cancer and birth defects registries and public involvement activities.

Workers

Voelz et al. conducted a historical cohort mortality study of 7,112 white male workers ever employed at Rocky Flats between 1952 and 1979 (HP 1983b:493-503).

Cause specific death rates in workers were compared with those in the U.S. white male population adjusted for age and calendar year. Statistically significant fewer deaths were observed than expected based on rates in the U.S. population from all causes (SMR=0.54, 95 percent CI=0.49-0.60), all cancers (SMR=0.64, 95 percent CI=0.52 0.77), digestive organs/peritoneal cancer (SMR=0.66, 95 percent CI=0.44-0.95), and respiratory cancer (SMR=0.58, 95 percent CI=0.40-0.80). Benign and unspecified neoplasms were the only cause of death significantly elevated in these workers with eight cases observed, (SMR=3.32, 95 percent CI=1.43-6.53). All eight tumors were intracranial. The cohort was then stratified by exposure to Pu. Among Pu exposed workers, significantly fewer deaths than expected were observed from all causes of death (SMR=0.38, 95 percent CI=0.31-0.46), all malignant neoplasms (SMR=0.41, 95 percent CI=0.23-0.59), and respiratory cancer (SMR=0.20, 95 percent CI=0.05-0.52). No cases of bone cancer were observed. Workers not exposed to Pu also showed significantly fewer deaths from all causes and all cancers.

Workers exposed to external radiation had significantly fewer deaths from all causes (SMR=0.49, 95 percent CI=0.43-0.54), all cancers (SMR=0.58, 95 percent CI=0.46-0.73), and respiratory cancer (SMR=0.57, 95 percent CI=0.37-0.83) than expected when compared with U.S. white males. Six of the total eight cases of benign and unspecified neoplasms occurred in workers exposed to external radiation. Two occurred in those exposed to Pu.

To investigate whether brain tumor mortality was associated with exposure to internally deposited Pu or external radiation, Reyes et al. conducted a case-control study of all primary brain tumor deaths that occurred among white males who had been employed at Rocky Flats between 1952 and 1977, and died between 1952 and 1980 (JOM 1984b:721-725). Sixteen cases were identified. Four controls were matched to each case on year of birth and period of employment. Demographic data and detailed work histories were obtained from employment records. Exposure data for internally deposited Pu and external radiation data were obtained from Rocky Flats Plant health physics records.

No statistically significant association was found between brain tumor mortality and exposure to Pu or cumulative external radiation exposure. No significant dose response trends were observed for any job or work area. The authors noted that the study was limited by the small number of cases in the study and the small proportion (10 percent) of the cohort who had died.

Tietjen presented mortality data on all causes of death, all cancer deaths, and lung cancer deaths for Rocky Flats workers with exposures greater than 74 Bq (2.0 nanocuries [nCi]) (HP 1987a:625-628). No excess mortality was observed, with fewer deaths from all causes (SMR=0.70, 95 percent CI=0.54-0.89) and lung cancer (SMR=0.14, 95 percent CI=0.0-0.76) than expected compared with U.S. rates. When compared to an internal comparison group, the Risk Ratio (RR) for mortality from all causes was 1.16 (95 percent CI=0.89-1.52) and for lung cancer it was 0.21 (95 percent CI=0.03-1.26).

To further elucidate the risks from exposure to low levels of Pu and external radiation, Wilkinson et al. studied the cohort of workers employed at Rocky Flats between 1952 and 1979 (AJE 1987d:231-250). The analyses were limited to 5,413 white males who were employed for at least 2 years at Rocky Flats. Workers with cumulative exposures >1 rem were considered exposed to external radiation; those with body burdens ≥2 nCi were considered exposed to Pu.

Compared with death rates among white males in the United States, significantly fewer deaths were observed than expected from all causes (SMR=0.62, 90 percent CI=0.57-0.68), all cancers (SMR=0.71, 90 percent CI=0.59-0.84), diseases of the circulatory system (SMR=0.61, 90 percent CI=0.54-0.69), accidents, poisonings,

and violence (SMR=0.65, 90 percent CI=0.51-0.81). As reported earlier by Voelz et al., benign and unspecified neoplasms were the only cause of death significantly elevated (SMR=3.16, 90 percent CI=1.77-7.07). Workers with Pu body burdens of ≥2 nCi were then compared with workers with less exposure. As cancers take varying times to develop, analyses were conducted considering induction periods of 2, 5, and 10 years. No significant excesses were seen for a 2-year induction period. After a 5-year induction period, significant increases from all causes (RR=1.33, 90 percent CI=1.05-1.68) and lymphopoietic cancer (RR=9.86, 90 percent CI=1.26-94.03) were observed. After 10 years, the excess in death from leukemia was no longer statistically significant (RR=5.22, 90 percent CI=0.57-38.8).

Similar analyses were conducted for workers who received 1 rem or more of external radiation compared with workers less exposed. Workers with ≥1 rem had statistically significant fewer deaths from all cancers, when compared with those with <1 rem. No dose-response relationships for Pu or external radiation were found. The authors noted nonstatistically significant increases in myeloid leukemia, lymphosarcoma and reticulum cell sarcoma, liver neoplasms, and unspecified brain tumors in workers with ≥1 rem of external radiation compared with workers with <1 rem.

Gilbert et al. conducted a combined cohort mortality analysis of white male workers employed at Hanford, Oak Ridge, or Rocky Flats for at least 6 months and monitored for exposure to external radiation (RR 1989a:19-35). Analyses for Rocky Flats were based on the same vital status and cause of death information reported by Wilkinson et al. To eliminate overlap, those who worked at multiple facilities were included in the analysis for the facility where they first met eligibility requirements; doses accumulated at other facilities were excluded. To allow for minimum latency (the time between exposure and the diagnosis of cancer), cumulative dose was lagged 2 years for leukemia and 10 years for other cancers. Expected death rates were derived from age and calendar specific death rates for U.S. white males.

In Rocky Flats workers monitored for external radiation, significantly fewer deaths were observed than expected from all causes, lung cancer, circulatory diseases, respiratory diseases excluding pneumonia, cirrhosis, and external causes. Consistent with previous studies of this cohort, benign and unspecified neoplasms of the brain were the only cause of death significantly elevated (SMR=3.84, 95 percent CI=1.5, 7.9). Unmonitored workers had a borderline statistically significant excess mortality from all cancers (SMR=1.6, 90 percent CI=1.0-2.5) but did not differ from monitored workers with respect to site-specific cancer mortality.

Analyses of mortality by cumulative radiation dose found no indication of increased cancer deaths with increased radiation dose, but a significant positive association was observed between noncancer mortality and radiation exposure. The authors indicated that mortality from circulatory diseases and external causes were contributors to this correlation with noncancer mortality. The authors concluded that there was no evidence of a correlation between chronic low-dose radiation exposure and mortality from all cancer or from leukemia.

In 1993, Gilbert et al. published an update of their previous analyses of data from Hanford, Oak Ridge, and Rocky Flats (RR 1993a:408-421). Four additional years of mortality data for the Rocky Flats cohort were included in this later analysis. As in the previous analysis, the study was limited to white males employed for at least 6 months and monitored for external radiation. All analyses were based on internal comparisons of death rates by level of radiation dose, as internal comparisons were considered by the authors to be less subject to bias and more likely to detect risks resulting from radiation exposure than were comparisons to external populations. Workers were included in the analyses beginning with the year after initial employment plus 5 years, or the first year of monitoring, whichever occurred later.

The previously observed correlation between noncancer mortality and external radiation exposure in Rocky Flats workers was no longer statistically significant, and external causes of death were now negatively correlated with radiation dose. Benign and unspecified neoplasms of the brain, which had been shown to be elevated in previous papers by Voelz and Wilkinson, remained elevated and showed no evidence of any dose

response relationship with external radiation. Deaths from leukemia indicated a positive correlation with external radiation exposure at Rocky Flats, but not at two other facilities considered in the analyses.

An international effort to pool data from populations exposed to external radiation included Rocky Flats workers, as well as workers at Hanford and Oak Ridge in the United States and other radiation worker populations in Canada and Britain (RR 1995a:117-132). The cohort was comprised of 95,673 workers employed 6 months or longer and the population dose was 3,543.2 Sv. There was no evidence of an association between radiation dose and mortality from all causes or from all cancers. There was a significant dose-response relationship with leukemia, excluding chronic lymphocytic leukemia (ERR=2.18 per Sv; 90 percent CI 0.1-5.7) and multiple myeloma (excess relative risk not computed; 44 observed). The authors concluded that the study results did not suggest that current radiation risk estimates for cancer at low levels of exposure are appreciable in error.

Epidemiologic Studies

The Department's Office of Epidemiologic Studies has implemented an epidemiologic surveillance program at Rocky Flats to monitor the health of current workers. This program will evaluate the occurrence of illness and injury in the workforce on a continuing basis and the results will be issued in annual reports. The implementation of this program will facilitate an ongoing assessment of the health and safety of Rocky Flats' workforce and will help identify emerging health issues.

Currently operational at a number of DOE sites, including production sites and R&D facilities, epidemiologic surveillance uses routinely collected health data including descriptions of illness resulting in absences lasting 5 or more consecutive workdays, disabilities, and OSHA recordable injuries and illnesses abstracted from the OSHA 200 log. These health event data, coupled with demographic data about the active workforce at the participating sites, are analyzed to evaluate whether particular occupational groups are at increased risk of disease or injury when compared with other workers at a site. As the program continues and data for an extended period of time become available, time trend analysis will become an increasingly important part of the evaluation of worker health. Monitoring the health of the workforce provides a baseline determination of the illness and injury experience of workers and a tool for monitoring the effects of changes made to improve the safety and health of workers. Noteworthy changes in the health of the workforce may indicate the need for more detailed study or increased health and safety measures to ensure adequate protection for workers.

Memorandum of Understanding

The Department entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites, and the Centers for Disease Control and Prevention became responsible for conducting dose reconstructions in several host States, including Idaho. NIOSH is responsible for worker studies. These activities are funded by DOE. A number of studies of the Rocky Flats' workforce are ongoing under the Memorandum of Understanding.

A study is currently underway by NIOSH, under a cooperative agreement with the State of Colorado, to update the Rocky Flats cohort mortality and cancer incidence among Rocky Flats workers. This study should be completed in 1997.

The University of Colorado is conducting a sentinel exposure event surveillance/evaluation at DOE sites. This study will develop a sentinel exposure event surveillance and evaluation system for exposures to chemicals and both ionizing and non-ionizing radiation in the defense nuclear industry. The pilot will start at Rocky Flats in 1997.

The National Jewish Center for Immunology and Respiratory Medicine is conducting a study of lung fibrosis in Pu workers at Rocky Flats. The goal of the study is to confirm that Pu workers are at increased risk for

developing radiographic abnormalities consistent with fibrosis; to determine the relationship between Pu-239 and other radionuclide and chemical exposures and the development of lung fibrosis; and to determine the frequency of fibrosis on lung biopsies of Rocky Flats workers compared to biopsies from nonexposed individuals and to relate the clinical, physiologic, and pathologic severity to radionuclide dose.

Under a cooperative agreement with the State of Colorado, a study is being conducted of the relationship between the different types of leukemia commonly diagnosed in children and parental exposure to ionizing radiation used in medical procedures and received through occupational exposure.

M.4.9 LOS ALAMOS NATIONAL LABORATORY

Los Alamos and adjacent counties comprise a unique setting and history. The LANL for much of its existence was a closed community where most of the residents had direct economic ties to the Laboratory. Nearly all male residents and some of the female residents are employed at LANL. Medical care in Los Alamos County had been centralized at the Laboratory and a single community hospital. This is a unique, highly educated community situated adjacent to lands populated by Native Americans.

Surrounding Communities. Selected cancer mortality and incidence (newly diagnosed cancer) rates between 1950-1969, for eleven selected cancers among white males in Los Alamos County were compared with rates for the State of New Mexico, the United States five "socioeconomic and occupational" control counties, and five high education Western counties," based on U.S. Bureau of the Census information (ER 1981a:86-105). The comparisons were made to identify cancer types that were greater than expected while taking into account important factors, such as income and education, associated with cancer patterns. Six cancer types were identified that had rates greater than cancer rates for one or more of the four comparison groups; they are: cancer of the bile ducts and liver; bladder; prostate; brain and nervous system; lympho- and reticulo-sarcoma; and leukemia. Cancer rates of the prostate, bladder, and leukemia were also greater than expected.

Compared with New Mexico white males, Los Alamos County Anglo-white males show non-statistically significant excesses in cancer incidence from 1969-1974 for the stomach colon, rectum, pancreas, lung, and bladder (ER 1981a:86-105). All cancers combined show a 35 percent statistically significant excess. Los Alamos County white females show non-statistically significant excesses for cancer of the stomach, large intestine, lymphosarcoma and reticulosarcoma, and leukemia. All cancers combined show a statistically significant 40 percent excess.

In 1991, the New Mexico Department of Health initiated epidemiologic studies in response to citizen concerns about an apparent excess of brain tumors among residents of the western area neighborhood of Los Alamos County as a result of historical LANL nuclear operations. The New Mexico Department of Health conducted a descriptive study of brain cancer incidence in Los Alamos County and for 22 other sites (NM DOH 1993a). The study showed that during the mid- to late- 1980s an approximate 80 percent excess of brain cancer had occurred in Los Alamos County compared with a New Mexico reference population and national statistics. The excess incidence had disproportionately occurred among persons who were residents of the western area at the time of diagnosis or death; however, there were only three cases and they were confined to the 2-year time period, 1986 and 1987. Additional descriptive studies showed that the brain cancer rates for Los Alamos County were within the range of rates observed across New Mexico counties from 1983-1987 and 1988-1991. A review of mortality statistics for benign or unspecified neoplasms of the brain and nervous system showed no deaths from these causes in Western Area residents during 1984-1990.

Los Alamos County breast cancer incidence rates remained level but higher than New Mexico rates from 1970-1990. Reproductive and demographic factors associated with the risk of breast cancer were thought to account for the higher rates. A special study was conducted to examine the recent increase in breast cancer since 1988 (NM DOH 1994a). The New Mexico Tumor Registry concluded that the increase seen in 1988-1992 was primarily due to increased detection of early stage disease.

The incidence of ovarian cancer in Los Alamos County women was elevated from the mid- 1970s to 1990. From 1986 through 1990, ovarian cancer incidence in Los Alamos County was roughly two-fold higher compared with New Mexico reference population rates. The excess ovarian cancer rate was confined to a census tract corresponding to two neighborhoods and was four to six-fold higher than that observed in the remaining Los Alamos County census tracts.

The incidence rates for melanoma (cancer of the skin) in Los Alamos County workers elevated from 1970 through 1990, with peak elevations occurring from the mid- to late-1980's. There was approximately a two-fold excess risk compared with a New Mexico State reference population. The excess melanoma incidence observed in Los Alamos County was thought to be related to the high ambient solar ultraviolet radiation intensity due to its high altitude.

A four-fold increase in thyroid cancer incidence during the late 1980s was noted in a study by Athas (NM DOH 1996a). A case-series records review was initiated to examine data relating to the detection, diagnosis, and known risk factors for thyroid cancer. All cases of thyroid cancer diagnosed among Los Alamos County residents between 1970 and 1995 were identified through the New Mexico Tumor Registry. The incidence rate for thyroid cancer in Los Alamos County was slightly higher than New Mexico rates between 1970 and the mid-1980's. There was a statistically-significant four-fold increase during the late-1980s and early 1990s compared with the State, but the rate began to decline in 1994 and 1995.

The higher than expected number of thyroid cancer cases could not be explained by changes in diagnosis of thyroid cancer among Los Alamos County residents. Additional analyses suggested that increased medical surveillance and greater access-to medical care were responsible for the recent excess in Los Alamos County. Potential risk factors for thyroid cancer including therapeutic irradiation, genetic susceptibility, occupational radiation exposure, and weight were also examined. However, the investigation did not identify a specific cause for the elevated rate of thyroid cancer in Los Alamos County.

Male Workers. A mortality study of 224 white males with the highest internal depositions of Pu 239 (10 nanocuries or more) at LANL were examined by Voelz, et al. (LANL 1985a). Followup was through April 1980; SMRs were low for all cause of death (SNM=0.56, 95 percent CI=0.40-0.75), all malignant neoplasms (SMR=0.54, 95 percent CI=0.23-1.06), compared with U.S. white males and lung cancer (SMR=20, 95 percent CI=0-110).

A cohort mortality study by Wiggs et al. examined the causes of death among 15,727 white males hired at LANL between 1943 and 1977 (HP 1994a:577-588). The purpose of the study was to determine if Pu deposition and external ionizing radiation were related to worker mortality. After nearly 30 years of followup, the LANL workforce experienced 37 percent fewer deaths from all causes, and 36 percent fewer deaths due to cancer than expected when compared with death rates for the U.S. population.

The researchers identified a subset of 3,775 workers who had been monitored for Pu exposure; of these, 303 workers were categorized as "exposed" based on a urine bioassay for Pu; the remainder were "non-exposed." One case of rare bone cancer, osteogenic sarcoma, a type of cancer related to Pu exposure in animal studies, was noted among the Pu exposed group. The overall mortality and site-specific rates of cancer did not differ significantly between the two groups of workers. A non-statistically significant increase in lung cancer among the exposed group was noted, but there was no information on cigarette use among the workers.

When researchers examined data for the 10,182 workers who were monitored for exposure to external ionizing radiation (including 245 workers exposed to Pu) they observed a dose-response relationship for cancers of the brain/central nervous system, cancer of the esophagus, and Hodgkin's disease. When the 225 Pu-exposed workers were excluded from the analysis, there was a statistically significant dose response between external ionizing radiation and kidney cancer and lymphocytic leukemia.

A special lifetime medical study was conducted on 26 of the workers who have the largest internal depositions of Pu at LANL. Voelz and Lawrence reported on the 42-year follow-up of the 26 white males who designed and built the first atomic bomb and were determined to have had a significant deposition of Pu-239 sometime in 1944 or 1945 based on job assignment, working conditions, and urine levels of Pu (HP 1991a:181-190). Their mortality experience was compared to U.S. white males adjusted for age and calendar time. The mortality rates were also compared with rates for a cohort of Los Alamos workers hired at the same time and born between the same years; no significant differences were observed for all cause mortality and all cancer mortality. One of the seven reported deaths was due to bone sarcoma, the most frequent radiation-induced cancer observed in persons with radium depositions.

Wiggs reported on 6,970 women employed at LANL at least 6 months from 1943 through 1979, with deaths determined through 1981 (LA Wiggs 1987a). The mortality rates for all causes of death combined and all cancers combined were 24 percent and 22 percent below the rate for the U.S. population. Although the overall rates are low, women occupationally exposed to ionizing radiation have elevated rates for cancer of the ovary and of the pancreas relative to those not exposed. An unusual finding was that female radiation workers experienced a statistically significant excess of death from suicide. In a special in-depth study, the suicides were compared to two control groups, deaths from other injuries and deaths from non-injuries. History of employment as a radiation worker was significantly associated with death from suicide for both comparison groups. No significant associations for duration of employment, Pu exposure, or marital status were seen (APHA 1988a).

As a result of a reported three-fold excess of malignant melanoma among laboratory workers at LLNL in California and similarities between occupational exposures and prevailing sunshine conditions at LANL and LLNL, an investigation was undertaken to assess the risk of melanoma at LANL (Lancet 198la:712-716). Incidence data were obtained from the New Mexico Tumor Registry. No excess risk for melanoma was detected at LANL among 11,308 laboratory workers between 1969 and 1978. Six cases were identified where about 5.7 were expected (Lancet 1982a:883-884). The rate for the total cohort, Hispanic males and females, non-Hispanic males and females were not significantly different from the corresponding New Mexico rates.

A special in-depth, study of fifteen cases diagnosed through 1982 did not detect an association between melanoma and exposure to any type of external radiation as measured by film badges, neutron exposures, Pu body burden based on urine samples, or employment as a chemist or physicist (HP 1983c:587-592). However, the melanoma cases were more educated than the comparison group using the college and graduate degree as a measure of education; a finding consistent with other reports of malignant melanoma according to the authors. The numbers in this study are too small to detect any but large excesses.

Memorandum of Understanding. The Department entered into a Memorandum of Understanding with the Department of Health and Human Services to conduct health studies at DOE sites. NIOSH is responsible for managing or conducting the worker studies. The following multi-site studies that include LANL are currently underway: a study of mortality among female nuclear weapons workers; a case-control study of multiple myeloma; a leukemia study; and an exposure assessment of hazardous waste/cleanup workers.

M.5 FACILITY ACCIDENTS

M.5.1 EVALUATION METHODOLOGIES AND ASSUMPTIONS

M.5.1.1 Introduction

The potential for facility accidents and the magnitudes of their consequences are important factors in the evaluation of the storage and disposition alternatives addressed in the PEIS. The health risk issues are twofold:

- Whether accidents at any of the individual storage and disposition facilities (or reasonable combinations thereof) pose unacceptable health risks to workers or the general public.

- Whether alternative locations for storage and disposition facilities (or reasonable combinations thereof) can provide lesser public or worker health risks. These lesser risks may arise either from a greater isolation of the site from the public, or from a reduced frequency of such external accident initiators as seismic events, aircraft crashes, and so forth.

Guidance for implementation of Council on Environmental Quality regulation 40 CFR 1502.22, as amended (51 FR 15618) requires the evaluation of impacts which have low probability of occurrence but high consequences if they do occur; thus facility accidents must be addressed to the extent feasible in the PEIS. Further, public comments received during the scoping process clearly indicated the public concern with facility safety and consequent health risks, and the need to address these concerns in the decisionmaking process.

For the No Action case, potential accidents are defined in existing facility documentation, such as safety analysis reports, hazards assessment documents, NEPA documents and probabilistic risk assessments. The accidents include radiological and chemical accidents that produce high consequences but have a low likelihood of occurrence, and a spectrum of other accidents that have a higher likelihood of occurrence and lesser consequences than the high consequence accidents. The data in these documents includes accident scenarios, materials at risk, source terms (quantities of hazardous materials released to the environment) and consequences.

For new storage and disposition facilities, the identification of accident scenarios and associated data would normally be a product of safety analysis reports performed on completed facility designs. However, the conceptual design information available during the PEIS preparation is not useful for quantitative safety analyses. Accordingly, for each of the storage and disposition facilities, the accident information developed for similar existing facilities is used as a surrogate and the likelihood and consequences (which are site dependent) are recomputed for each of the storage and disposition proposed sites where a facility may be located. This calculation reflects the effects of such site parameters as population size and distribution, meteorology and distance to the site boundary.

This analysis also acknowledges, semi-quantitatively, the differences in likelihood of accident initiators at specific sites (for example, aircraft impacts, beyond evaluation basis seismic events) as well as qualitatively discussing the opportunities for risk reduction afforded by the potential incorporation of new technologies, processes or protective features in the storage and disposition facilities that will enhance public health and safety over the existing facilities. Subsequent to the PEIS, evaluation of the specific benefits achieved by such measures would be presented in the tiered, project-specific environmental impact statement for each facility. Also, for each facility, a *Hazards Analysis Document* that identifies and estimates the effects of all major hazards that have the potential to affect the environment, workers and the public would be issued in conjunction with the Conceptual Design Package. Additional accident analyses for identified major hazards would be provided in a *Preliminary Safety Analysis Report* to be issued during the period of Definitive Design (Title II) Review. A *Final Safety Analysis Report* would be prepared during the construction period and issued before testing begins

as final documented evidence that the new facility can be operated in a manner that does not present any undo risk to the health and safety of workers and the public.

In determining the potential for facility accidents and the magnitudes of their consequences, this PEIS incorporates two important concepts to the presentation of results: risk and uncertainties and conservatism.

M.5.1.1.1 *Risk*

Risk is most important when presenting accident analysis results. The chance that an accident might occur during the conduct of an operation is called the probability of occurrence. An event that is certain to occur has a probability of 1 (as in 100 percent certainty). The probability of occurrence of an accident is less than one because accidents, by definition, are not certain to occur. If an accident is expected to happen once every 5 years, the frequency (and probability) of occurrence is 0.2/yr (1 occurrence ÷ 5 years = 0.2 occurrences/yr).

Once the frequency (occurrences per year) and the consequences (for radiation effects, measured in terms of the number of latent cancer fatalities caused by the radiation exposure) of an accident are known, the risk can be determined. The risk of latent cancer fatalities per year is the product of the annual frequency of occurrence times the number of latent cancer fatalities that would result if the accident occurred. This annual risk expresses the expected number of latent cancer fatalities per year, taking account of both the annual chance that an accident might occur and the estimated consequences if it does occur.

For example, if the frequency of an accident were 0.2 occurrences/yr and the number of latent cancer fatalities resulting from the accident were 0.05, the risk would be 0.01 latent cancer fatalities/yr (0.2 occurrences/yr x 0.05 latent cancer fatalities per occurrence = 0.01 latent cancer fatalities/yr). Another way to express this risk (0.01 latent cancer fatalities/yr) is to note that if the operation subject to the accident continued for 100 years, one latent cancer fatality would be likely to occur because of accidents during that period. This is equivalent to 1 chance in 100 that a single latent cancer fatality would be caused by the accident source for each year of operation.

A frame of reference for the risks from accidents associated with storage and disposition alternatives can be developed in the same way. As an example, the risk of a latent cancer fatality from a beyond evaluation basis earthquake (the maximum radiation exposure consequence) for a hypothetical individual at the INEL site boundary from the consolidation of Pu would be approximately 2.7×10^{-11} ($1.0 \times 10^{-7} \times 2.7 \times 10^{-4}$)/yr (Table M.5.2.1.2–3). This risk can be compared with the lifetime risks of death from other accidental causes to gain a perspective. For example, the risk of dying from a motor vehicle accident is about 1 in 80. Similarly, the risk of death for the average American from fires is approximately 1 in 500, and for death from accidental poisoning, the risk is about 1 in 1,000. These comparisons are not meant to imply that risks of a latent cancer fatality caused by DOE operations are trivial, only to show how they compare with other, more common risks. Radiological risks to the general public from DOE operations are considered to be involuntary risks, as opposed to voluntary risks such as operating a motor vehicle.

M.5.1.1.2 *Uncertainties and Conservatism*

[Text deleted.] For routine operations, the results of monitoring actual operations provide realistic estimates of source terms, which when combined with conservative estimates of the effects of radiation, produce estimates of risk that are very unlikely to be exceeded. The effects for all alternatives have been calculated using uniform source terms and other factors, so this PEIS provides an appropriate means of comparing potential impacts on human health and the environment.

The analyses of hypothetical accidents are based on calculations that in turn are based on sequences of events and models of effects that have not occurred. The models provide estimates of the probabilities, source terms, pathways for dispersion and exposure, and the effects on human health and the environment that are as realistic

as possible. In many cases, the probability of the accidents postulated is very low and little experience is available; thus, the consequences are uncertain. This has required the use of models or values for input that produce estimates of consequences and risks that are higher than would actually occur in order to provide conservative results. All the alternatives have been evaluated using uniform methods and data, allowing a fair comparison of all the alternatives on the same basis. [Text deleted.]

M.5.1.2 Safety Design Process

One of the major design goals for storage and disposition facilities is to achieve a reduced risk to worker and public health and safety relative to that associated with similar operations at the existing nuclear weapons complex. Significant changes exist between storage and disposition facilities and the current facilities design criteria and safety standards, which would reduce total risk to the public. These changes include: design to current DOE structural and safety criteria; smaller throughput, batch size and inventories of certain hazardous materials; and elimination of the same hazardous materials. This would reduce potential offsite health effects if a significant accidental release were to occur.

Storage and disposition facilities would be designed to comply with current Federal, State and local laws, DOE Orders, and industrial codes and standards. This would provide a plant that is highly resistant to the effects of natural phenomena, including earthquake, flood, tornado, high wind, as well as credible events as appropriate to the site, such as fire and explosions, and man-made threats to its continuing structural integrity for containing hazardous materials. The facilities would be designed to maintain their continuing structural integrity in the event of any credible accident or event, including an aircraft crash.

The design process for the storage and disposition facilities would comply with the requirements for safety analysis and evaluation in DOE O 430.1 and Order 5480.23. These require that the safety assessment be an integral part of the design process to ensure compliance with all DOE safety criteria by the time that the facilities are constructed and in operation.

The safety analysis process begins early in conceptual design with identification of hazards having potential to produce unacceptable safety consequences to workers or the public. As the design develops, failure mode and effects analyses are performed to identify events which have the potential to release hazardous material. The kinds of events considered include equipment failure, spills, human error, fire, explosions, criticality, earthquake, electrical storms, tornado, flood, and aircraft crash. These postulated events become focal points for design changes or improvements to prevent unacceptable accidents. These analyses continue as the design progresses to assess the need for safety equipment and to assess the performance of this equipment in accident mitigation. Eventually, the safety analyses are formally documented in a safety analysis report (SAR) and, if appropriate, in a probabilistic risk assessment (PRA). The PRA documents the estimated frequency and consequence for a complete spectrum of accidents and helps to identify where design improvements could make meaningful safety improvements.

The first SAR is completed at the conclusion of conceptual design and includes identification of hazards and some limited assessment of a few enveloping evaluation basis accidents. This analysis includes deterministic safety analysis and failure modes and effects analysis of major systems. A detailed comprehensive preliminary SAR is completed by the completion of preliminary design and provides a broad assessment of the range of evaluation basis accident scenarios and the performance of equipment provided in the facility specifically for accident consequence mitigation. A limited PRA may be included in that analysis.

The SAR continues to be developed during detailed design. The safety review of this report and any supporting PRA is completed and safety issues resolved before initiation of construction of the facility. There is also a final SAR produced that includes documentation of safety-related design changes during construction and the impact of those changes on the safety assessment. It also includes the results of any safety-related research and

development that has been performed to support the safety assessment of the facility. Final approval of the final SAR is required before the facility is allowed to commence operation.

M.5.1.3 Analysis Methodology

M.5.1.3.1 *Introduction*

The MELCOR Accident Consequence Code System (MACCS) was used to estimate the consequences of all storage and disposition facilities for all accidents. A discussion of the MACCS computer code is provided in Section M.5.1.3.2. A detailed description of the MACCS model is available in NUREG/CR-6059, SAND92-2146. The MACCS computer code has been used for the analysis of accidents for many environmental impact statements and other safety documentations and is considered applicable for analyzing potential accidents associated with the storage and disposition of Pu and HEU.

M.5.1.3.2 *MACCS Overview*

MACCS models the offsite consequences of an accident that releases a plume of radioactive materials to the atmosphere. Should such an accidental release occur, the radioactive gases and aerosols in the plume would be transported by the prevailing wind while dispersing in the atmosphere. The environment would be contaminated by radioactive materials deposited from the plume and the population would be exposed to radiation. An estimation of the range and probability of the health effects induced by the radiation exposures not avoided by protective actions and the economic costs and losses that would result from the contamination of the environment are the objectives of a MACCS calculation.

There are two fundamental aspects of the organization of MACCS which are basic to its understanding: the time scale after the accident is divided into various "phases;" and the region surrounding the reactor is divided into a polar-coordinate grid.

The time scale after the accident is divided into three phases: emergency phase, intermediate phase, and long-term phase. The emergency phase begins immediately after the accident and could last up to seven days following the accident. In this period, the exposure of population to both radioactive clouds and contaminated ground is modeled. Various protective measures can be specified for this phase, including evacuation, sheltering, and dose-dependent relocation.

The intermediate phase can be used to represent a period in which evaluations are performed and decisions are made regarding the type of protective measure actions which need to be taken. In this period, the radioactive clouds are assumed to be gone and the only exposure pathways are those from the contaminated ground. The protective measure which can be taken during this period is temporary relocation.

The long-term phase represents all time subsequent to the intermediate phase. The only exposure pathways considered here are those resulting from the contaminated ground. A variety of protective measures can be taken in the long-term phase in order to reduce doses to acceptable levels: decontamination, interdiction, and condemnation of property.

The spatial grid used to represent the region is centered on the facility itself. The user specifies the number of radial divisions as well as their endpoint distances. Up to 35 of these divisions may be defined, extending out to a maximum distance of 9,999 km (6,213 mi). The angular divisions used to define the spatial grid correspond to the sixteen directions of the compass.

Since the emergency phase calculations utilize dose-response models for early fatality and early injury which are highly non-linear, it is necessary for those calculations to be performed on a finer grid than the calculations

of the intermediate and long-term phases. For this reason, the sixteen compass sectors are divided into three, five, or seven user-specified subdivisions in the calculations of the emergency phase.

The dose-to-risk conversion factors (0.0005 latent cancer fatalities/person-rem for the public and 0.0004 for the worker) used in this PEIS to relate radiation exposures to latent cancer fatalities are based on the *1990 Recommendations of the International Commission on Radiation Protection* (ICRP Publication 60). These conversion factors are consistent with those used by the U.S. NRC in its rulemaking "Standards for Protection Against Radiation" (10 CFR 20). In developing these conversion factors, the International Commission on Radiological Protection reviewed many studies, including *Health Effects of Exposure to Low Levels of Ionizing Radiation (BEIR V)* and *Sources, Effects and Risks of Ionizing Radiation*. These conversion factors represent the best-available estimates for relating a dose to its effect; most other conversion factors fall within the range of uncertainty associated with the conversion factors that are discussed in the National Academy of Sciences NAS/NRC (1990). The conversion factors apply where the dose to an individual is less than 20 rem (20,000 millirem [mrem]) and the dose rate is less than 10 rem (10,000 mrem) per hour. At doses greater than 20 rem (20,000 mrem), the conversion factors used to relate radiation doses to latent cancer fatalities are doubled. At much higher doses, prompt effects, rather than latent cancer fatalities, may be the primary concern. Unusual accident situations that may result in high radiation doses to individuals are considered special cases.

The MACCS code was applied in a probabilistic manner using a weather bin sampling technique. Centerline doses as a function of distance were calculated for each of 150 meteorological sequence samples; the mean value of these doses and increased likelihoods of cancer fatality for the distance corresponding to the location of the maximum offsite individual (sometimes referred to as the "maximum exposed individual") at each site were reported for that individual. Doses to an uninvolved worker were calculated similarly, except that the worker would experience an increased likelihood of cancer fatality of 4.0×10^{-4} times the dose in rem for doses less than 20 rem or exposure rates less than 10 rem/hr. For larger doses, when the rate of exposure is greater than 10 rem/hr, the increased likelihood of latent cancer fatality is doubled. The estimated dose to a worker was based on a location 1,000 m (3,280 ft) from the release point.

Offsite population doses and latent cancer fatalities are calculated by MACCS using a similar methodology to that described for the maximum offsite individual. In the case of the population, each of the sampled meteorological sequences was applied to each of the 16 sectors (accounting for the frequency of occurrence of the wind blowing in that direction). Population doses are the sum of the individual doses in each sector. Once again, the mean value of the calculated population doses and latent cancer fatalities for each of these trials is reported.

M.5.1.3.3 *Methodology and Techniques*

The relative consequences of postulated accidents in the evaluation of each alternative are assessed in the Public and Occupational Health and Safety Sections of Section 4.2 for the storage alternatives and Section 4.3 for the disposition alternatives. The accident analysis involves less detail than a formal probabilistic risk assessment and facility safety analysis by addressing bounding accidents (relatively low probability of occurrence and high consequence) and a representative spectrum of possible operational accidents (relatively high probability of occurrence and low consequence). The technical approach for the selection of accidents is consistent with the DOE Office of NEPA Oversight *Recommendation for the Preparation of Environmental Assessments and Environmental Impact Statement* guidance, which recommends consideration of two major categories of accidents: within design basis accidents and beyond design basis accidents.

The preliminary accident analyses (conducted during the feasibility design) were performed primarily to identify those systems and structures which should be categorized as "safety class." This determination, for a particular system or structure, involves assessing whether the consequence of an accident in which that system

or structure fails exceeds some threshold exposure value. In general, the consequence assessments are very conservative to ensure that cost estimates which result from the feasibility design have a conservative basis.

In developing a range of accidents to consider, it is common to consider only those accidents that have a probability of occurrence equal to or greater than 10^{-7} per year. The accidents evaluated were selected to represent a spectrum of accident probabilities and consequences ranging from low-probability/high-consequence to high-probability/low-consequence events. However, because of the preliminary nature of the designs under consideration here, it has not been possible to assess quantitatively the probability of occurrence of all of the events addressed. The information provided does not indicate the total risk of operating the facility but does provide information identifying high risk events that could be used to differentiate safety risks among alternatives if an accident were to occur. The probabilities for the accidents described have been estimated by considering qualitatively accident probabilities from other facilities and locations. It is possible that the beyond design basis accidents included for consideration here will later be shown in tiered NEPA documentation to have probabilities of occurrence much less than 10^{-7}.

For each potential accident, information is provided on the risk and consequences to three types of receptors: (1) a worker, (2) a maximally exposed individual member of the public, and (3) the offsite population. The first receptor, a worker, is a hypothetical individual working on the site but not involved in the proposed action. This worker is assumed to be located at a point 1,000 m (3,280 ft)from the location of the accident. Although other distances closer to the accident could have been assumed, the results would be less accurate because of limitations of the MACCS computer code in modeling the effects of building and local terrain on the dispersion of the released radioactive substances. A worker that is closer than 1,000 m (3,280 ft) from the accident will generally receive a higher dose, while a worker further away would generally receive a lower dose. At some sites where the distance from the accident to the nearest site boundary is less than 1,000 m (3,280 ft), the worker is assumed to be located at the site boundary. The second receptor, a member of the public, is a hypothetical individual who is assumed to be located at the nearest site boundary. Exposures received by this individual are intended to represent the highest risks to a member of the public. The third receptor, the offsite population, represents all members of the public located within 80 km (50 mi) of the location of the accident. The choice of 80 km (50 mi) is a common practice, although other distances could have been used.

The consequences of an accident for a worker or individual at the site boundary are expressed in terms of dose (rem) and probability of a cancer fatality if the individual is exposed to the dose. The risk of cancer fatality to the individual is the mathematical product of the probability of the accident and the consequence (probability of a cancer fatality). The consequences for the offsite population are expressed in terms of population dose (person-rem) and the number of cancer fatalities in the population within 80 km (50 mi) of the site boundary. The risk of the estimated number of cancer fatalities is the mathematical product of the number of cancer fatalities and the probability of the accident. The estimated risks are expressed either on an annual basis or on the basis of the operational campaign proposed or assumed for a storage or disposition facility, depending on the context of the information.

The MACCS model is one of a number of models that could be used for accident evaluations. The models will generally differ in their results because of the many differences in their assumptions and techniques. The MACCS model was selected because it is commonly used for SAR and EIS accident analyses, particularly for severe accident analyses. For each of the accidents selected for evaluation of an alternative, information is provided on the accident probability, dose, cancer fatalities, and risk.

M.5.1.3.4 *Isotopic Spectra Used in the Storage and Disposition Accident Analyses*

For each of the accidents selected for evaluation of an alternative, source term information (radionuclide release) is generated based on the total Pu release using the pertinent radionuclide spectrum for that alternative. A mixed Pu spectrum presented in Table M.5.1.3.4–1 is used for Pu storage and disposition alternatives. A

weapons grade Pu spectrum presented in Table M.5.1.3.4–2 is used for Pit Disassembly and Conversion operations. The Pu spectrum presented in Table M.5.1.3.4–3 is used for Pu conversion process operations.

Table M.5.1.3.4–1. Isotopic Distribution for a Mixed Plutonium Release[a]

Isotope	Isotopic Content (g/g Pu)	Specific Activity of Isotope (Ci/g Isotope)	Specific Activity (Ci/g Pu)
Pu-238	9.21×10^{-5}	17.1	1.58×10^{-3}
Pu-239	0.921	0.0621	0.0572
Pu-240	0.0666	0.228	0.0152
Pu-241	5.23×10^{-4}	103	0.0539
Pu-242	5.69×10^{-4}	3.93×10^{-3}	2.23×10^{-6}
Am-241	8.28×10^{-5}	3.43	2.84×10^{-4}

[a] Isotopic distribution for mixed Pu aged for 60 years. Used for calculating the source terms for the accidents evaluated for Pu storage and disposition alternatives.

Note: Am=Americium.

Source: HNUS 1996a.

Table M.5.1.3.4–2. Isotopic Distribution for a Weapons-Grade Plutonium Release[a]

Isotope	Isotopic Content (g/g Pu)	Specific Activity of Isotope (Ci/g Isotope)	Specific Activity (Ci/g Pu)
Pu-238	3.29×10^{-5}	17.1	5.63×10^{-4}
Pu-239	0.930	0.0621	0.0578
Pu-240	0.0596	0.228	0.0136
Pu-241	4.19×10^{-4}	103	0.0430
Pu-242	1.0×10^{-4}	3.93×10^{-3}	3.93×10^{-7}
Am-241	6.63×10^{-3}	3.43	0.0227

[a] Isotopic distribution for weapons-grade Pu aged for 60 years. Used for calculating the source terms for the potential accidents evaluated for pit disassembly process operations.

Note: Am=Americium.

Source: HNUS 1996a.

Table M.5.1.3.4–3. Isotopic Distribution for a Non-Pit (Pu Conversion) Plutonium Release[a]

Isotope	Isotopic Content (g/g Pu)	Specific Activity of Isotope (Ci/g Isotope)	Specific Activity (Ci/g Pu)
Pu-238	2.12×10^{-4}	17.1	3.62×10^{-3}
Pu-239	0.902	0.0621	0.0560
Pu-240	0.0807	0.228	0.0184
Pu-241	7.35×10^{-4}	103	0.0757
Pu-242	1.51×10^{-3}	3.93×10^{-3}	5.94×10^{-6}
Am-241	1.16×10^{-4}	3.43	3.99×10^{-4}

[a] Isotopic distribution for non-pit (Pu conversion) Pu aged for 60 years. Used for calculating the source terms for the potential accidents evaluated for Pu conversion process operations.

Note: Am=Americium.

Source: HNUS 1996a.

M.5.2 LONG-TERM STORAGE ALTERNATIVES

M.5.2.1 Consolidation of Plutonium Alternative

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for the consolidated Pu storage facility in the *Beyond Design Basis Accident Analysis*. The studies postulated a set of accident scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risks that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than 1.0×10^{-7}/yr are anticipated that will have consequences and risks larger than those described in this section. [Text deleted.] This includes the potential impacts of an aircraft crash which has been considered and dismissed because the probability of crashing into a single facility and causing sufficient damage to release Pu is much lower than 10^{-7}/yr.

M.5.2.1.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, three evaluation basis accidents and seven beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.2.1.1–1 and M.5.2.1.1–2. Accident scenario descriptions are provided in Table M.5.2.1.1–3. Accident source term information is provided in Tables M.5.2.1.1–4 and M.5.2.1.1–5.

[Text deleted.]

Table M.5.2.1.1–1. Evaluation Basis Accident Scenarios for Consolidation Alternative

Accident Scenario	Accident Frequency (per year)	Source Term at Risk[a] (PCV)	Source Term Released to Environment (g Pu)
PCV puncture by forklift	6.0×10^{-4}	2	0.0387
PCV breach by firearms discharge	3.5×10^{-4}	1	3.87×10^{-3}
PCV penetration by corrosion	0.064	1	0.158

[a] Primary containment vessel (PCV) is assumed to contain up to 4,500 g of weapons-grade Pu as a bounding case.
Source: DOE 1995mm.

Table M.5.2.1.1–2. Beyond Evaluation Basis Accident Scenarios for Consolidation Alternative

Accident Scenario	Accident Frequency (per year)	Source Term at Risk[a] (PCV)	Source Term Released to Environment
Vault fire	1.0×10^{-7}	120	81.3 g Pu
Truck bay fire	1.0×10^{-7}	12	5.40 g Pu
Spontaneous combustion	7.0×10^{-7}	2	7.75×10^{-3} g Pu
Explosion in the vault	1.0×10^{-7}	45	12.7 g Pu
Explosion outside of vault	1.0×10^{-7}	1	0.058 g Pu
Nuclear criticality	1.0×10^{-7}	[b]	1.0×10^{19} fissions[b]
Beyond evaluation basis earthquake	1.0×10^{-7}	194	146 g Pu

[a] Primary containment vessel (PCV) is assumed to contain up to 4,500 g of weapons-grade Pu as a bounding case.
[b] See Table M.5.2.1.1–5.
Source: DOE 1995mm.

Table M.5.2.1.1–3. Accident Scenario Descriptions for Consolidation and Collocation Facilities

Accident Scenario	Accident Description
Evaluation Basis Accidents	
PCV puncture by forklift	A forklift driver attempting to pick up a pallet containing PCVs in the shipping/receiving area encounters a situation in which the fork is incorrectly positioned such that it contacts the PCVs. Before the operator responds to the contact, the forward motion of the forklift punctures two PCVs with the tines of the fork. The operator backs the forklift away from the structure, and the PCVs fall off the fork, spilling some of the contents on the floor.
PCV breach by firearms discharge	Because of the armed security guard force at the storage facility, it is necessary to consider possible breach of a PCV caused by a bullet from accidental discharge of the guard's firearm. The PCV is not designed to withstand such an impact, and its effect would be to potentially penetrate the container and cause some dispersal of the contents. This can occur only where the PCVs are above the operating floor, and would be most likely in the shipping/receiving area and possibly some material handling areas.
PCV penetration by corrosion	The PCV is presumed to fail because of long-term corrosion, gradual buildup of internal pressure, or other causes generally internal to the PCV itself, and probably related to its contents. These events would generally be the result of errors in packaging the contents or in sealing the PCV. The failure would take place over an extended period, and the initial progress of the failure would be undetectable through casual external observation. Eventually, the PCV closure seal would be breached and a small slit or crack would develop. The opening would be enlarged through continuation of the driving force and eventually some PCV contents would be expelled into the storage area or into one of the handling/inspection areas.
Beyond Evaluation Basis Accidents	
Vault fire	A large amount of jet fuel, gasoline, or some high energy density fuel is introduced into the vault through a ventilation duct and ignited.
Truck bay fire	A fire occurs following the rupture of the a truck's fuel tank and ignition of the spilled fuel. A single trailer is engulfed by flames and is heated to at least the ignition point of Pu.
Spontaneous combustion	Due to improper packaging, the contents of two PCVs ignite spontaneously after being punctured by a forklift accident.
Explosion in the vault	An explosion of undefined origin is assumed to occur below grade in the vault. The detonation is assumed to deform some storage tubes, which in turn crush and open some PCVs. There is no fire and other systems remain intact.
Explosion outside of vault	An explosion of undefined origin is assumed to occur in the repackaging area. The blast has sufficient force to breach the glovebox, exposing the contents to the room atmosphere and bypassing two levels of filtration material.
Nuclear criticality	The only way a criticality event could occur would be in the case of multiple operational errors or an accident scenario that breaches PCVs and the fissile material somehow collects in a criticality favorable geometry.
Beyond evaluation basis earthquake	The building collapses and some PCVs are crushed.

Note: PCV=primary containment vessel.
Source: DOE 1995mm.

Table M.5.2.1.1–4. Consolidation Alternative Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario		
	PCV Puncture by Forklift	PCV Breach by Firearms Discharge	PCV Penetration by Corrosion
Frequency of occurrence (per year)	6.0×10^{-4}	3.5×10^{-4}	6.4×10^{-2}
Pu released to environment (g)	0.0387	3.87×10^{-3}	0.158
Isotope Released to Environment (Ci)			
Pu-238	6.11×10^{-5}	6.11×10^{-6}	2.50×10^{-4}
Pu-239	2.21×10^{-3}	2.21×10^{-4}	9.04×10^{-3}
Pu-240	5.88×10^{-4}	5.88×10^{-5}	2.40×10^{-3}
Pu-241	2.09×10^{-3}	2.09×10^{-4}	8.52×10^{-3}
Pu-242	8.63×10^{-8}	8.63×10^{-9}	3.52×10^{-7}
Am-241	1.10×10^{-5}	1.10×10^{-6}	4.49×10^{-5}

Note: Am=Americium; PCV=primary containment vessel.
Source: Derived from Tables M.5.1.3.4–1 and M.5.2.1.1–1.

Table M.5.2.1.1–5. Consolidation Alternative Beyond Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario						
	Vault Fire	Truck Bay Fire	Spontaneous Combustion	Explosion in the Vault	Explosion Outside of Vault	Nuclear Criticality	Beyond Evaluation Basis Earthquake
Frequency of occurrence (per year)	1.0×10^{-7}	1.0×10^{-7}	7.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
Pu released to environment (g)	81.3	5.40	7.75×10^{-3}	12.69	0.058	NA	146.39
Fission	NA	NA	NA	NA	NA	1.0×10^{19}	NA
Isotope Released to Environment (Ci)							
Pu-238	0.128	8.53×10^{-3}	1.22×10^{-5}	0.020	9.16×10^{-5}	0	0.231
Pu-239	4.65	0.309	4.43×10^{-4}	0.726	3.32×10^{-3}	0	8.37
Pu-240	1.24	0.082	1.18×10^{-4}	0.193	8.82×10^{-4}	0	2.23
Pu-241	4.38	0.291	4.18×10^{-4}	0.684	3.13×10^{-3}	0	7.89
Pu-242	1.81×10^{-4}	1.20×10^{-5}	1.73×10^{-8}	2.83×10^{-5}	1.29×10^{-7}	0	3.26×10^{-4}
Am-241	0.023	1.53×10^{-3}	2.20×10^{-6}	3.60×10^{-3}	1.65×10^{-5}	0	4.16×10^{-2}
Kr-83m	0	0	0	0	0	55.0	0
Kr-85m	0	0	0	0	0	35.5	0
Kr-85	0	0	0	0	0	4.05×10^{-3}	0
Kr-87	0	0	0	0	0	215	0
Kr-88	0	0	0	0	0	115	0
Kr-89	0	0	0	0	0	6.5×10^{3}	0
Xe-131	0	0	0	0	0	0.05	0
Xe-133m	0	0	0	0	0	1.10	0
Xe-133	0	0	0	0	0	13.5	0
Xe-135m	0	0	0	0	0	1.65×10^{3}	0
Xe-135	0	0	0	0	0	205	0
Xe-137	0	0	0	0	0	2.45×10^{4}	0
Xe-138	0	0	0	0	0	5.5×10^{3}	0
I-131	0	0	0	0	0	0.55	0
I-132	0	0	0	0	0	60.0	0
I-133	0	0	0	0	0	8.0	0
I-134	0	0	0	0	0	215	0
I-135	0	0	0	0	0	22.5	0

[Text deleted.]

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1 and M.5.2.1.1–2.

M.5.2.1.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.2.1.2–1 through M.5.2.1.2–5. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 using the MACCS computer code. [Text deleted].

Table M.5.2.1.2–1. Consolidation Alternative Accident Impacts at Hanford Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	**Dose (rem)**	**Probability of Cancer Fatality[a]**	**Dose (rem)**	**Probability of Cancer Fatality[a]**	**Dose (person-rem)**	**Number of Cancer Fatalities[b]**	**Accident Frequency (per year)**
PCV puncture by forklift	0.011	4.4×10^{-6}	8.8×10^{-5}	4.4×10^{-8}	0.64	3.2×10^{-4}	6.0×10^{-4}
PCV breach by firearms discharge	1.1×10^{-3}	4.4×10^{-7}	8.8×10^{-6}	4.4×10^{-9}	0.064	3.2×10^{-5}	3.5×10^{-4}
PCV penetration by corrosion	0.045	1.8×10^{-5}	3.6×10^{-4}	1.8×10^{-7}	2.6	1.3×10^{-3}	6.4×10^{-2}
Vault fire	23.1	0.012	0.18	9.2×10^{-5}	1,340	0.67	1.0×10^{-7}
Truck bay fire	1.5	6.1×10^{-4}	0.012	6.1×10^{-6}	89	0.045	1.0×10^{-7}
Spontaneous combustion	2.2×10^{-3}	8.8×10^{-7}	1.8×10^{-5}	8.8×10^{-9}	0.13	6.4×10^{-5}	7.0×10^{-7}
Explosion in the vault	3.6	1.4×10^{-3}	0.029	1.4×10^{-5}	209	0.11	1.0×10^{-7}
Explosion outside of vault	0.016	6.6×10^{-6}	1.3×10^{-4}	6.6×10^{-8}	0.96	4.8×10^{-4}	1.0×10^{-7}
Nuclear criticality	0.010	4.2×10^{-6}	6.5×10^{-5}	3.3×10^{-8}	0.07	3.5×10^{-5}	1.0×10^{-7}
Beyond evaluation basis earthquake	41.6	0.022	0.33	1.7×10^{-4}	2,410	1.2	1.0×10^{-7}
[Text deleted]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values; PCV=primary containment vessel.

Source: Calculated using the source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 and the MACCS computer code.

Table M.5.2.1.2–2. Consolidation Alternative Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
PCV puncture by forklift	7.5×10^{-3}	3.0×10^{-6}	1.4×10^{-4}	7.0×10^{-8}	0.014	7.2×10^{-6}	6.0×10^{-4}
PCV breach by firearms discharge	7.5×10^{-4}	3.0×10^{-7}	1.4×10^{-5}	7.0×10^{-9}	1.4×10^{-3}	7.2×10^{-7}	3.5×10^{-4}
PCV penetration by corrosion	0.031	1.2×10^{-5}	5.7×10^{-4}	2.9×10^{-7}	0.059	3.0×10^{-5}	6.4×10^{-2}
Vault fire	15.8	7.6×10^{-3}	0.29	1.5×10^{-4}	30.3	0.015	1.0×10^{-7}
Truck bay fire	1.0	4.2×10^{-4}	0.019	9.7×10^{-5}	2.0	1.0×10^{-3}	1.0×10^{-7}
Spontaneous combustion	1.5×10^{-3}	6.0×10^{-7}	2.8×10^{-5}	1.4×10^{-8}	2.9×10^{-3}	1.5×10^{-6}	7.0×10^{-7}
Explosion in the vault	2.5	9.9×10^{-4}	0.046	2.3×10^{-5}	4.7	2.4×10^{-3}	1.0×10^{-7}
Explosion outside of vault	0.011	4.5×10^{-6}	2.1×10^{-4}	1.0×10^{-7}	0.021	1.1×10^{-5}	1.0×10^{-7}
Nuclear criticality	7.7×10^{-3}	3.1×10^{-6}	1.3×10^{-4}	6.5×10^{-8}	1.4×10^{-3}	6.9×10^{-7}	1.0×10^{-7}
Beyond evaluation basis earthquake	28.4	0.015	0.53	2.6×10^{-4}	55	0.027	1.0×10^{-7}
[Text deleted]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values; PCV=primary containment vessel.

Source: Calculated using the source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 and the MACCS computer code.

Table M.5.2.1.2–3. Consolidation Alternative Accident Impacts at Idaho National Engineering Laboratory

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
PCV puncture by forklift	0.010	4.1×10^{-6}	8.8×10^{-5}	4.4×10^{-8}	0.19	9.6×10^{-5}	6.0×10^{-4}
PCV breach by firearms discharge	1.0×10^{-3}	4.1×10^{-7}	8.8×10^{-6}	4.4×10^{-9}	0.19	9.6×10^{-6}	3.5×10^{-4}
PCV penetration by corrosion	0.042	1.7×10^{-5}	3.6×10^{-4}	1.8×10^{-7}	0.78	3.9×10^{-4}	6.4×10^{-2}
Vault fire	21.6	0.011	0.19	9.3×10^{-5}	402	0.20	1.0×10^{-7}
Truck bay fire	1.4	5.7×10^{-4}	0.012	6.2×10^{-6}	26.7	0.013	1.0×10^{-7}
Spontaneous combustion	2.1×10^{-3}	8.2×10^{-7}	1.8×10^{-5}	8.9×10^{-9}	0.038	1.9×10^{-5}	7.0×10^{-7}
Explosion in the vault	3.4	1.3×10^{-3}	0.029	1.5×10^{-5}	62.7	0.031	1.0×10^{-7}
Explosion outside of vault	0.015	6.2×10^{-6}	1.3×10^{-4}	6.7×10^{-8}	0.29	1.4×10^{-4}	1.0×10^{-7}
Nuclear criticality	0.010	4.0×10^{-6}	7.7×10^{-5}	3.9×10^{-8}	0.018	9.0×10^{-6}	1.0×10^{-7}
Beyond evaluation basis earthquake	38.9	0.021	0.34	1.7×10^{-4}	723	0.36	1.0×10^{-7}
[Text deleted]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values; PCV=primary containment vessel.

Source: Calculated using the source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 and the MACCS computer code.

Table M.5.2.1.2–4. Consolidation Alternative Accident Impacts at Pantex Plant

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
PCV puncture by forklift	4.4×10^{-3}	1.8×10^{-6}	1.4×10^{-3}	7.1×10^{-7}	0.22	1.1×10^{-4}	6.0×10^{-4}
PCV breach by firearms discharge	4.4×10^{-4}	1.8×10^{-7}	1.4×10^{-4}	7.1×10^{-8}	0.022	1.1×10^{-5}	3.5×10^{-4}
PCV penetration by corrosion	0.018	7.2×10^{-6}	5.8×10^{-3}	2.9×10^{-6}	0.89	4.4×10^{-4}	6.4×10^{-2}
Vault fire	9.3	3.8×10^{-3}	3.0	1.5×10^{-3}	456	0.23	1.0×10^{-7}
Truck bay fire	0.62	2.5×10^{-4}	0.20	9.9×10^{-5}	303	0.015	1.0×10^{-7}
Spontaneous combustion	8.9×10^{-4}	3.5×10^{-7}	2.8×10^{-4}	1.4×10^{-7}	0.044	2.2×10^{-5}	7.0×10^{-7}
Explosion in the vault	1.5	5.8×10^{-4}	0.46	2.3×10^{-4}	71.2	0.036	1.0×10^{-7}
Explosion outside of vault	6.6×10^{-3}	2.7×10^{-6}	2.1×10^{-3}	1.1×10^{-6}	0.33	1.6×10^{-4}	1.0×10^{-7}
Nuclear criticality	4.8×10^{-3}	1.9×10^{-6}	1.9×10^{-3}	9.3×10^{-7}	0.046	2.3×10^{-5}	1.0×10^{-7}
Beyond evaluation basis earthquake	16.7	7.5×10^{-3}	5.34	2.7×10^{-3}	821	0.41	1.0×10^{-7}
[Text deleted]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values; PCV=primary containment vessel.

Source: Calculated using the source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 and the MACCS computer code.

Table M.5.2.1.2–5. Consolidation Alternative Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
PCV puncture by forklift	7.2×10^{-3}	2.9×10^{-6}	1.4×10^{-4}	7.1×10^{-8}	0.068	3.4×10^{-4}	6.0×10^{-4}
PCV breach by firearms discharge	7.2×10^{-4}	2.9×10^{-7}	1.4×10^{-5}	7.1×10^{-9}	0.068	3.4×10^{-5}	3.5×10^{-4}
PCV penetration by corrosion	0.029	1.2×10^{-5}	5.8×10^{-4}	2.9×10^{-7}	2.8	1.4×10^{-3}	6.4×10^{-2}
Vault fire	15.2	6.9×10^{-3}	0.3	1.5×10^{-4}	1,440	0.72	1.0×10^{-7}
Truck bay fire	1.0	4.0×10^{-4}	0.020	9.9×10^{-6}	95.5	0.048	1.0×10^{-7}
Spontaneous combustion	1.4×10^{-3}	5.8×10^{-7}	2.8×10^{-5}	1.4×10^{-8}	0.14	6.9×10^{-5}	7.0×10^{-7}
Explosion in the vault	2.4	9.4×10^{-4}	0.046	2.3×10^{-5}	224	0.11	1.0×10^{-7}
Explosion outside of vault	0.011	4.3×10^{-6}	2.1×10^{-4}	1.1×10^{-7}	1.0	5.1×10^{-4}	1.0×10^{-7}
Nuclear criticality	6.9×10^{-2}	2.8×10^{-6}	1.1×10^{-4}	5.7×10^{-8}	0.094	4.7×10^{-5}	1.0×10^{-7}
Beyond evaluation basis earthquake	27.3	0.013	0.53	2.7×10^{-4}	2,590	1.3	1.0×10^{-7}
[Text deleted]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values; PCV=primary containment vessel.

Source: Calculated using the source terms in Tables M.5.2.1.1–4 and M.5.2.1.1–5 and the MACCS computer code.

M.5.3 DISPOSITION ALTERNATIVES

M.5.3.1 Pit Disassembly/Conversion Facility

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a pit disassembly/conversion facility in the *Fissile Material Disposition Program PEIS Data Call Input Report: Pit Disassembly and Conversion Facility.* The studies postulated a set of accident scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risks that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than $1.0x10^{-7}$/yr are anticipated that will have consequences and risks larger than those described in this section. [Text deleted.]

M.5.3.1.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, four evaluation basis accidents and four beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.1.1–1 and M.5.3.1.1–2. Accident source term information is provided in Tables M.5.3.1.1–3 through M.5.3.1.1–5. Descriptions of the accident scenarios are provided in Table M.5.3.1.1–6.

Table M.5.3.1.1–1. Evaluation Basis Accident Scenarios for the Pit Disassembly/Conversion Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Fire on the loading dock	$1.0x10^{-4}$ to $1.0x10^{-3}$	18 g Pu	0.8 g Pu
Fire in a process cell	$1.0x10^{-5}$ to $1.0x10^{-3}$	24 g Pu	$4.8x10^{-6}$ g Pu
Deflagration inside a glovebox	$1.0x10^{-5}$ to $1.0x10^{-3}$	10 kg Pu	$1.0x10^{-3}$ g Pu
Impact induced spill	$4.5x10^{-5}$	4 kg PuO_2	$1.7x10^{-9}$ g Pu

Source: LANL 1996d.

Table M.5.3.1.1–2. Beyond Evaluation Basis Accident Scenarios for the Pit Disassembly/Conversion Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Nuclear criticality	$<1.0x10^{-7}$	$5.0x10^{17}$ fissions; gaseous by-products released[a]	[a]
Beyond design basis fire in a process cell	$<1.0x10^{-7}$	24 g Pu	0.034 g Pu
Oxyacetylene explosion in a process cell	$<1.0x10^{-7}$	10 kg Pu	50 g Pu
Beyond evaluation basis earthquake	$<1.0x10^{-7}$	10 kg Pu	25 g Pu

[a] See Table M.5.3.1.1–3.
Source: LANL 1996d.

Table M.5.3.1.1–3. Pit Disassembly/Conversion Facility Criticality Source Terms

Nuclide	Produced (Ci)	Released (Ci)
Kr-83m	5.5	5.5
Kr-85m	3.55	3.55
Kr-85	4.05×10^{-4}	4.05×10^{-4}
Kr-87	21.5	21.5
Kr-88	11.5	11.5
Kr-89	650	650
Xe-131m	5.0×10^{-3}	5.0×10^{-3}
Xe-133m	0.11	0.11
Xe-133	1.35	1.35
Xe-135m	165	165
Xe-135	20.5	20.5
Xe-137	2,450	2,450
Xe-138	550	550
I-131	0.55	0.138
I-132	60	15
I-133	8	2.0
I-134	215	53.8
I-135	22.5	5.36

Source: LANL 1996d.

Table M.5.3.1.1–4. Pit Disassembly/Conversion Facility Evaluation Basis Accident Source Terms

	Accident Scenario			
Accident Parameter	Fire on Loading Dock	Beyond Design Basis Fire in Process Cell	Deflagration Inside a Glovebox	Impact Induced Spill
Frequency of occurrence (per year)	5.0×10^{-4a}	1.0×10^{-4a}	1.0×10^{-4a}	4.5×10^{-5}
Pu released to environment (g)	0.8	4.8×10^{-6}	1.0×10^{-3}	1.7×10^{-9}
Isotope Released to Environment (Ci)				
Pu-238	4.50×10^{-4}	2.70×10^{-9}	5.63×10^{-7}	9.57×10^{-13}
Pu-239	0.0462	2.77×10^{-7}	5.78×10^{-5}	9.83×10^{-11}
Pu-240	0.0109	6.53×10^{-8}	1.36×10^{-5}	2.31×10^{-11}
Pu-241	0.0344	2.06×10^{-7}	4.30×10^{-5}	7.31×10^{-11}
Pu-242	3.14×10^{-7}	1.88×10^{-12}	3.92×10^{-10}	6.66×10^{-16}
Am-241	0.0182	1.09×10^{-7}	2.27×10^{-5}	3.86×10^{-11}

[a] Midpoint of the estimated frequency range.

Source: Derived from Tables M.5.1.3.4–2 and M.5.3.1.1–1.

Table M.5.3.1.1–5. Pit Disassembly/Conversion Facility Beyond Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario			
	Nuclear Criticality	Beyond Design Basis Fire in a Process Cell	Oxyacetylene Explosion in a Process Cell	Beyond Design Basis Earthquake
Frequency of occurrence (per year)[a]	$1.0x10^{-7}$	$1.0x10^{-7}$	$1.0x10^{-7}$	$1.0x10^{-7}$
Pu released to environment (g)	NA	0.034	50	25
Fissions	$5.0x10^{17}$	NA	NA	NA
Isotope Released to Environment (Ci)				
Pu-238	0	$1.91x10^{-5}$	0.0281	0.0141
Pu-239	0	$1.97x10^{-3}$	2.89	1.44
Pu-240	0	$4.62x10^{-4}$	0.680	0.340
Pu-241	0	$1.46x10^{-3}$	2.15	1.08
Pu-242	0	$1.34x10^{-8}$	$1.96x10^{-5}$	$9.80x10^{-6}$
Am-241	0	$7.72x10^{-4}$	1.13	0.567
Kr-83m	5.5	0	0	0
Kr-85m	3.55	0	0	0
Kr-85	$4.05x10^{-4}$	0	0	0
Kr-87	21.5	0	0	0
Kr-88	11.5	0	0	0
Kr-89	650	0	0	0
Xe-131m	$5.0x10^{-3}$	0	0	0
Xe-133m	0.11	0	0	0
Xe-133	1.35	0	0	0
Xe-135m	165	0	0	0
Xe-135	20.5	0	0	0
Xe-137	$2.45x10^{3}$	0	0	0
Xe-138	550	0	0	0
I-131	0.138	0	0	0
I-132	15	0	0	0
I-133	2.0	0	0	0
I-134	53.8	0	0	0
I-135	5.36	0	0	0

[a] Maximum value of the estimated frequency range.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–2, M.5.3.1.1–2, and M.5.3.1.1–3.

Table M.5.3.1.1–6. Accident Scenario Descriptions for the Pit Disassembly/Conversion Facility

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Fire on the loading dock	The fire is caused by welding, cleaning solvents, electrical shorts, or other miscellaneous causes. The scenario assumes an open garage door and that a single drum of combustible waste is involved in the fire.
Fire in a process cell	It is assumed that a process cell contains a glovebox used for final processing of plutonium oxide powder. The gloves, stowed outside the glovebox, are coated with a layer of Pu dust. A flammable cleaning liquid such as acetone or isopropyl alcohol is brought into the process cell in violation of operating procedures, spills, and ignites. The initial extent and intensity of the fire are sufficient to completely incinerate the gloves. The sprinkler system activates and protects the glovebox from further damage. The ventilation system with HEPA filters continues to function throughout the accident.
Deflagration inside a glovebox	The bounding evaluation basis explosion is a deflagration of a flammable gas mixture inside a glovebox. It is assumed that through some unforeseen set of failures, a combustible gas mixture accumulates inside a glovebox and is ignited, possibly by an electrical spark from an operating electrical device. The deflagration blows out the HEPA filter from the glovebox ventilation system exit. Gloves may also be blown out. The room volumes are sufficient to attenuate the pressure wave to levels below that needed to damage building ventilation system HEPA filters.
Impact induced spill	The most catastrophic case of leak or spill of nuclear material would result from a forklift or other large vehicle running over a package of nuclear material, breaching the containment, and causing airborne release to the room. Three stage HEPA filtration is available for the facility exhaust to limit the release to the environment.
Beyond Evaluation Basis Accidents	
Nuclear criticality	The postulated criticality accident was caused by improper stacking or handling of bulk nuclear material. Multiple operational errors in the material spacing, packing density, manner, and type of containment, and maximum quantities of fissile material permitted in the area would be required for postulated criticality accident to occur.
Beyond evaluation basis fire in a process cell	A typical fire with coincident failures of two or more major safety systems constitutes a beyond evaluation basis fire. The evaluation postulated the fire in a process cell, discussed above, with the sprinkler system and ventilation system with HEPA filtration inoperative during the accident.
Oxyacetylene explosion in a process cell	The evaluation postulated the explosion of a welding rig oxyacetylene bottle in a process cell. The explosion is sufficient to blow out the HEPA filters and cause significant damage to the ventilation system and nearby equipment.
Beyond evaluation basis earthquake	The following assumptions were used in the evaluation: (1) the earthquake disables the ventilation system; (2) there is sufficient structural damage to the building and it does not totally collapse; (3) a ceiling slab falls on the glovebox with the most material at risk and severely damages the glovebox; (4) the process cell with the most material at risk is located on an outside wall; (5) the outside wall cracks; and (6) the wind is blowing and the cracks are located on the lee side of the building.

Source: LANL 1996d.

M.5.3.1.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.3.1.2–1 through M.5.3.1.2–6. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 using the MACCS code. [Text deleted.]

Table M.5.3.1.2–1. Pit Disassembly/Conversion Facility Accident Impacts at Hanford Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.32	1.3×10^{-4}	0.010	5.1×10^{-6}	18.5	9.3×10^{-3}	5.0×10^{-5}
Fire in a process cell	1.9×10^{-6}	7.6×10^{-10}	6.1×10^{-8}	3.0×10^{-11}	1.1×10^{-4}	5.5×10^{-8}	1.0×10^{-4}
Deflagration inside a glovebox	4.0×10^{-4}	1.6×10^{-7}	1.3×10^{-5}	6.4×10^{-9}	0.023	1.2×10^{-5}	1.0×10^{-4}
Impact induced spill	6.8×10^{-10}	2.7×10^{-13}	2.2×10^{-11}	1.1×10^{-14}	3.9×10^{-8}	2.0×10^{-11}	4.5×10^{-5}
Nuclear criticality	1.7×10^{-3}	6.9×10^{-7}	5.7×10^{-5}	2.9×10^{-8}	0.016	7.8×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	0.014	5.4×10^{-6}	4.3×10^{-4}	2.2×10^{-7}	0.79	3.9×10^{-4}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	19.9	9.4×10^{-3}	0.63	3.2×10^{-4}	1150	0.58	1.0×10^{-7}
Beyond evaluation basis earthquake	9.9	4.1×10^{-3}	0.32	1.6×10^{-4}	576	0.29	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

Table M.5.3.1.2–2. Pit Disassembly/Conversion Facility Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.22	8.7×10^{-5}	4.0×10^{-3}	2.0×10^{-6}	0.42	2.1×10^{-4}	5.0×10^{-5}
Fire in a process cell	1.3×10^{-6}	5.2×10^{-10}	2.4×10^{-8}	1.2×10^{-11}	2.5×10^{-6}	1.3×10^{-9}	1.0×10^{-4}
Deflagration inside a glovebox	2.7×10^{-4}	1.1×10^{-7}	5.1×10^{-6}	2.5×10^{-9}	5.2×10^{-4}	2.6×10^{-7}	1.0×10^{-4}
Impact induced spill	4.6×10^{-10}	1.9×10^{-13}	8.6×10^{-12}	4.3×10^{-15}	8.9×10^{-10}	4.5×10^{-13}	4.5×10^{-5}
Nuclear criticality	1.3×10^{-3}	5.0×10^{-7}	2.2×10^{-5}	1.1×10^{-8}	3.2×10^{-4}	1.6×10^{-7}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	9.3×10^{-3}	3.7×10^{-6}	1.7×10^{-4}	8.6×10^{-8}	0.018	8.9×10^{-6}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	13.6	6.3×10^{-3}	0.25	1.3×10^{-4}	26.1	1.3×10^{-2}	1.0×10^{-7}
Beyond evaluation basis earthquake	6.8	2.7×10^{-3}	0.13	6.3×10^{-5}	13.0	6.5×10^{-3}	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

Table M.5.3.1.2–3. Pit Disassembly/Conversion Facility Accident Impacts at Idaho National Engineering Laboratory

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.30	1.2×10^{-4}	2.6×10^{-3}	1.3×10^{-6}	5.5	2.8×10^{-3}	5.0×10^{-5}
Fire in a process cell	1.8×10^{-6}	7.1×10^{-10}	1.5×10^{-8}	7.7×10^{-12}	3.3×10^{-5}	1.7×10^{-8}	1.0×10^{-4}
Deflagration inside a glovebox	3.7×10^{-4}	1.5×10^{-7}	3.2×10^{-6}	1.6×10^{-9}	6.9×10^{-3}	3.5×10^{-6}	1.0×10^{-4}
Impact induced spill	6.3×10^{-10}	2.5×10^{-13}	5.5×10^{-12}	2.7×10^{-15}	1.2×10^{-8}	5.9×10^{-12}	4.5×10^{-5}
Nuclear criticality	1.7×10^{-3}	6.7×10^{-7}	1.3×10^{-5}	6.7×10^{-9}	4.2×10^{-3}	2.1×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	0.013	5.1×10^{-6}	1.1×10^{-4}	5.5×10^{-8}	0.24	1.2×10^{-4}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	18.6	9.2×10^{-3}	0.16	8.0×10^{-5}	346	0.17	1.0×10^{-7}
Beyond evaluation basis earthquake	9.3	3.7×10^{-3}	0.080	4.0×10^{-5}	173	0.086	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

Table M.5.3.1.2–4. Pit Disassembly/Conversion Facility Accident Impacts at Pantex Plant

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.13	5.1×10^{-5}	0.041	2.0×10^{-5}	6.3	3.2×10^{-3}	5.0×10^{-5}
Fire in a process cell	7.7×10^{-7}	3.1×10^{-10}	2.5×10^{-7}	1.2×10^{-10}	3.8×10^{-5}	1.9×10^{-8}	1.0×10^{-4}
Deflagration inside a glovebox	1.6×10^{-4}	6.4×10^{-8}	5.1×10^{-5}	2.6×10^{-8}	7.9×10^{-3}	3.9×10^{-6}	1.0×10^{-4}
Impact induced spill	2.7×10^{-10}	1.1×10^{-13}	8.7×10^{-11}	4.3×10^{-14}	1.3×10^{-8}	6.7×10^{-12}	4.5×10^{-5}
Nuclear criticality	7.7×10^{-4}	3.1×10^{-7}	2.9×10^{-4}	1.4×10^{-7}	9.5×10^{-3}	4.8×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	5.5×10^{-3}	2.2×10^{-6}	1.7×10^{-3}	8.7×10^{-7}	0.27	1.3×10^{-4}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	8.0	3.3×10^{-3}	2.6	1.3×10^{-3}	393	0.20	1.0×10^{-7}
Beyond evaluation basis earthquake	4.0	1.6×10^{-3}	1.3	6.4×10^{-4}	196	0.098	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

Table M.5.3.1.2–5. Pit Disassembly/Conversion Facility Accident Impacts at Oak Ridge Reservation

	Worker at 772 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.37	1.5×10^{-4}	0.37	1.9×10^{-4}	69.3	0.035	5.0×10^{-5}
Fire in a process cell	2.2×10^{-6}	8.9×10^{-10}	2.2×10^{-6}	1.1×10^{-9}	4.2×10^{-4}	2.1×10^{-7}	1.0×10^{-4}
Deflagration inside a glovebox	4.7×10^{-4}	1.9×10^{-7}	4.7×10^{-4}	2.3×10^{-7}	0.087	4.3×10^{-5}	1.0×10^{-4}
Impact induced spill	7.9×10^{-10}	3.2×10^{-13}	7.9×10^{-10}	4.0×10^{-13}	1.5×10^{-7}	7.4×10^{-11}	4.5×10^{-5}
Nuclear criticality	2.0×10^{-3}	7.8×10^{-7}	2.0×10^{-3}	9.8×10^{-7}	0.13	6.6×10^{-5}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	0.016	6.3×10^{-6}	0.016	7.9×10^{-6}	3.0	1.5×10^{-3}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	23.3	1.1×10^{-2}	23.3	0.014	4,320	2.2	1.0×10^{-7}
Beyond evaluation basis earthquake	11.6	4.6×10^{-3}	11.6	5.8×10^{-3}	2,160	1.1	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary [772 m for this facility at ORR], whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

Table M.5.3.1.2–6. Pit Disassembly/Conversion Facility Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Fire on the loading dock	0.21	8.4×10^{-5}	4.1×10^{-3}	2.0×10^{-6}	19.8	9.9×10^{-3}	5.0×10^{-5}
Fire in a process cell	1.3×10^{-6}	5.0×10^{-10}	2.5×10^{-8}	1.2×10^{-11}	1.2×10^{-4}	5.9×10^{-8}	1.0×10^{-4}
Deflagration inside a glovebox	2.6×10^{-4}	1.0×10^{-7}	5.1×10^{-6}	2.6×10^{-9}	0.025	1.2×10^{-5}	1.0×10^{-4}
Impact induced spill	4.4×10^{-10}	1.8×10^{-13}	8.7×10^{-12}	4.4×10^{-15}	4.2×10^{-8}	2.1×10^{-11}	4.5×10^{-5}
Nuclear criticality	1.1×10^{-3}	4.5×10^{-7}	2.0×10^{-5}	1.0×10^{-8}	0.020	1.0×10^{-5}	1.0×10^{-7}
Beyond evaluation basis fire in a process cell	8.9×10^{-3}	3.6×10^{-6}	1.7×10^{-4}	8.7×10^{-8}	0.84	4.2×10^{-4}	1.0×10^{-7}
Oxyacetylene explosion in a process cell	13.0	5.8×10^{-3}	0.26	1.3×10^{-4}	1,240	0.62	1.0×10^{-7}
Beyond evaluation basis earthquake	6.5	2.8×10^{-3}	0.13	6.4×10^{-5}	618	0.31	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.1.1–4 and M.5.3.1.1–5 and the MACCS computer code.

M.5.3.2 Mixed Oxide Fuel Fabrication Facility

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a MOX fuel fabrication at DOE sites and a generic site in the *Fissile Material Disposition Program PEIS Data Call Input Report: Mixed Oxide Fuel Fabrication.* The studies postulated a set of accident scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risks that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than $1.0x10^{-7}$/yr are anticipated that will have consequences and risks larger than those described in this section. [Text deleted.]

M.5.3.2.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, four evaluation basis accidents and four beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.2.1–1 and M.5.3.2.1–2. Accident source term information is provided in Tables M.5.3.2.1–3 through M.5.3.2.1–5. Description of accident scenarios are provided in Table M.5.3.2.1–6.

Table M.5.3.2.1–1. Evaluation Basis Accident Scenarios for the Mixed Oxide Fuel Fabrication Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Fire on open loading dock	$1.0x10^{-4}$ to $1.0x10^{-3}$	18 g Pu	0.8 g Pu
Fire in process cell	$1.0x10^{-5}$ to $1.0x10^{-3}$	24 g Pu	$4.8x10^{-6}$ g Pu
Leaks or spills from breach of containment	$4.5x10^{-5}$	4 kg Pu	$1.7x10^{-9}$ g Pu
Explosion inside a glovebox	$1.0x10^{-5}$ to $1.0x10^{-3}$	10 kg Pu	$1.0x10^{-3}$ g Pu

Source: LANL 1996b.

Table M.5.3.2.1–2. Beyond Evaluation Basis Accident Scenarios for the Mixed Oxide Fuel Fabrication Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Nuclear criticality	$1.0x10^{-7}$	$5.0x10^{17}$ fissions; gaseous by-products released[a]	[a]
Beyond evaluation basis fire	$1.0x10^{-7}$	24 g Pu	0.034 g Pu
Beyond evaluation basis explosion	$1.0x10^{-7}$	10 kg Pu	50 g Pu
Beyond evaluation basis earthquake	$1.0x10^{-7}$	10 kg Pu	25 g Pu

[a] See Table M.5.3.2.1–3.
Source: LANL 1996b.

Table M.5.3.2.1–3. Mixed Oxide Fuel Fabrication Facility Criticality Source Terms

Nuclide	Produced (Ci)	Released (Ci)
Kr-83m	5.5	2.75
Kr-85m	3.5	1.75
Kr-85	4.0×10^{-4}	2.0×10^{-4}
Kr-87	21.5	11
Kr-88	11.5	6
Kr-89	650	325
Xe-131m	5.0×10^{-3}	2.5×10^{-3}
Xe-133m	0.1	0.05
Xe-133	1.5	0.75
Xe-135m	165	85
Xe-135	20.5	10
Xe-137	2,450	1,225
Xe-138	550	275
I-131	0.5	0.025
I-132	60	3
I-133	8	0.4
I-134	215	11
I-135	22.5	1.0

Source: LANL 1996b.

Table M.5.3.2.1–4. Mixed Oxide Fuel Fabrication Facility Evaluation Basis Accident Source Terms

	Accident Scenario			
Accident Parameter	Fire on Loading Dock	Fire in Process Cell	Leaks or Spills from Breach of Containment	Explosion Inside Glovebox
Frequency of occurrence (per year)	5.0×10^{-4}[a]	1.0×10^{-4}[a]	4.5×10^{-5}	1.0×10^{-4}[a]
Pu released to environment (g)	0.8	4.8×10^{-6}	1.7×10^{-9}	1.0×10^{-3}
Isotope Released to Environment (curies)				
Pu-238	4.50×10^{-4}	2.70×10^{-9}	9.57×10^{-13}	5.63×10^{-7}
Pu-239	0.0462	2.77×10^{-7}	9.83×10^{-11}	5.78×10^{-5}
Pu-240	0.0109	6.53×10^{-8}	2.31×10^{-11}	1.36×10^{-5}
Pu-241	0.0344	2.06×10^{-7}	7.31×10^{-11}	4.30×10^{-5}
Pu-242	3.14×10^{-7}	1.88×10^{-12}	6.66×10^{-16}	3.92×10^{-10}
Am-241	0.0182	1.09×10^{-7}	3.86×10^{-11}	2.27×10^{-5}

[a] Midpoint of the estimated frequency range.

Note: Am=Americium.

Source: Derived from Tables M.5.1.3.4–2 and M.5.3.2.1–1.

Table M.5.3.2.1–5. Mixed Oxide Fuel Fabrication Facility Beyond Evaluation Basis Accident Source Terms

	Accident Scenario			
Accident Parameter	**Nuclear Criticality**	**Beyond Evaluation Basis Fire**	**Beyond Evaluation Basis Explosion**	**Beyond Evaluation Basis Earthquake**
Frequency of occurrence (per year)	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}	1.0×10^{-7}
Pu released to environment (g)	NA	0.034	50	25
Fissions	5.0×10^{17}	NA	NA	NA
Isotope Released to Environment (Ci)				
Pu-238	0	1.91×10^{-5}	0.0281	0.0141
Pu-239	0	1.97×10^{-3}	2.89	1.44
Pu-240	0	4.62×10^{-4}	0.680	0.340
Pu-241	0	1.46×10^{-3}	2.15	1.08
Pu-242	0	1.33×10^{-8}	1.96×10^{-5}	9.80×10^{-6}
Am-241	0	7.72×10^{-4}	1.13	0.567
Kr-83m	2.75	0	0	0
Kr-85m	1.75	0	0	0
Kr-85	2.0×10^{-4}	0	0	0
Kr-87	11	0	0	0
Kr-88	6	0	0	0
Kr-89	325	0	0	0
Xe-131m	2.5×10^{-3}	0	0	0
Xe-133m	0.05	0	0	0
Xe-133	0.75	0	0	0
Xe-135m	85	0	0	0
Xe-135	10	0	0	0
Xe-137	1,225	0	0	0
Xe-138	275	0	0	0
I-131	0.025	0	0	0
I-132	3	0	0	0
I-133	0.4	0	0	0
I-134	11	0	0	0
I-135	1.0	0	0	0

Note: NA=not applicable.
Source: Derived from Tables M.5.1.3.4–2, M.5.3.2.1–2, and M.5.3.2.1–3.

Table M.5.3.2.1–6. Accident Scenario Descriptions for the Mixed Oxide Fuel Fabrication Facility

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Fire on the loading dock	The fire is caused by welding, cleaning solvents, electrical shorts, or other miscellaneous causes. The scenario assumes an open garage door and that a single drum of combustible waste is involved in the fire.
Fire in a process cell	It is assumed that a process cell contains a glovebox used for final processing of plutonium oxide powder. The gloves, stowed outside the glovebox, are coated with a layer of Pu dust. A flammable cleaning liquid such as acetone or isopropyl alcohol is brought into the process cell in violation of operating procedures, spills, and ignites. The initial extent and intensity of the fire are sufficient to completely incinerate the gloves. The sprinkler system activates and protects the glovebox from further damage. The ventilation system with HEPA filters continues to function throughout the accident.
Deflagration inside a glovebox	The bounding evaluation basis explosion is a deflagration of a flammable gas mixture inside a glovebox. It is assumed that through some unforeseen set of failures, a combustible gas mixture accumulates inside a glovebox and is ignited, possibly by an electrical spark from an operating electrical device. The deflagration blows out the HEPA filter from the glovebox ventilation system exit. Gloves may also be blown out. The room volumes are sufficient to attenuate the pressure wave to levels below that needed to damage the building ventilation system HEPA filters.
Impact-induced spill	The most catastrophic case of leak or spill of nuclear material would result from a forklift or other large vehicle running over a package of nuclear material, breaching the containment, and causing an airborne release to the room. Three-stage HEPA filtration is available for the facility exhaust to limit the release to the environment.
Beyond Evaluation Basis Accidents	
Nuclear criticality	There will not be sufficient quantities of plutonium solutions at the facility to cause a criticality accident. The most likely cause of a criticality event involving Pu oxides would be improper stacking or handling of bulk nuclear material. Multiple operational errors in the material spacing, packing density, manner, and type of containment, and maximum quantities of fissile material permitted in the area would be required for the postulated criticality accident to occur.
Beyond evaluation basis fire in a process cell	A typical fire with coincident failures of two or more major safety systems constitutes a beyond evaluation basis fire. The evaluation postulated the fire in a process cell, discussed above, with the sprinkler system and ventilation system with HEPA filtration inoperative during the accident.
Oxyacetylene explosion in a process cell	The evaluation postulated the explosion of a welding rig oxyacetylene bottle in a process cell. The explosion is sufficient to blow out the HEPA filters and cause significant damage to the ventilation system and nearby equipment.
Beyond evaluation basis earthquake	The following assumptions were used in the evaluation: (1) the earthquake disables the ventilation system; (2) there is significant structural damage to the building but it does not totally collapse; (3) a ceiling slab fall on the glovebox with the most material at risk and severely damages the glovebox; (4) the process cell with the most material at risk is located on an outside wall; (5) the outside wall cracks and the cracks; and (6) the wind is blowing and the cracks are located on the lee side of the building.

Source: LANL 1996b.

M.5.3.2.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.3.2.2–1 through M.5.3.2.2–6. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.2.1–4 and M.5.3.2.1–5 using the MACCS computer code. [Text deleted.]

Table M.5.3.2.2–1. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Hanford Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.32	1.3×10^{-4}	0.010	5.1×10^{-6}	18.5	9.3×10^{-3}	5.0×10^{-4}
Evaluation basis fire in process cell	1.9×10^{-6}	7.6×10^{-10}	6.1×10^{-8}	3.0×10^{-11}	1.1×10^{-4}	5.5×10^{-8}	1.0×10^{-4}
Leaks or spills from breach of containment	6.8×10^{-10}	2.7×10^{-13}	2.2×10^{-11}	1.1×10^{-14}	3.9×10^{-8}	2.0×10^{-11}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	4.0×10^{-4}	1.6×10^{-7}	1.3×10^{-5}	6.4×10^{-9}	0.023	1.2×10^{-5}	1.0×10^{-4}
Nuclear criticality	5.2×10^{-4}	2.1×10^{-7}	1.7×10^{-5}	8.4×10^{-9}	3.4×10^{-3}	1.7×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire	0.014	5.4×10^{-6}	4.3×10^{-4}	2.2×10^{-7}	0.79	3.9×10^{-4}	1.0×10^{-7}
Beyond evaluation basis explosion	19.9	9.4×10^{-3}	0.63	3.2×10^{-4}	1150	0.58	1.0×10^{-7}
Beyond evaluation basis earthquake	9.9	4.1×10^{-3}	0.32	1.6×10^{-4}	576	0.29	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

Table M.5.3.2.2–2. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.22	8.7×10^{-5}	4.0×10^{-3}	2.0×10^{-6}	0.42	2.1×10^{-4}	5.0×10^{-4}
Evaluation basis fire in process cell	1.3×10^{-6}	5.2×10^{-10}	2.4×10^{-8}	1.2×10^{-11}	2.5×10^{-6}	1.3×10^{-9}	1.0×10^{-4}
Leaks or spills from breach of containment	4.6×10^{-10}	1.8×10^{-13}	8.6×10^{-12}	4.3×10^{-15}	8.9×10^{-10}	4.5×10^{-13}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	2.7×10^{-4}	1.1×10^{-7}	5.1×10^{-6}	2.5×10^{-9}	5.2×10^{-4}	2.6×10^{-7}	1.0×10^{-4}
Nuclear criticality	3.9×10^{-4}	1.5×10^{-7}	6.5×10^{-6}	3.3×10^{-9}	6.6×10^{-5}	3.3×10^{-8}	1.0×10^{-7}
Beyond evaluation basis fire	9.3×10^{-3}	3.7×10^{-6}	1.7×10^{-4}	8.6×10^{-8}	0.018	8.9×10^{-6}	1.0×10^{-7}
Beyond evaluation basis explosion	13.6	6.3×10^{-3}	0.25	1.3×10^{-4}	26.1	0.013	1.0×10^{-7}
Beyond evaluation basis earthquake	6.8	2.7×10^{-3}	0.13	6.3×10^{-5}	13.0	6.5×10^{-3}	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

Table M.5.3.2.2–3. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Idaho National Engineering Laboratory

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.30	1.2×10^{-4}	2.6×10^{-3}	1.3×10^{-6}	5.5	2.8×10^{-3}	5.0×10^{-4}
Evaluation basis fire in process cell	1.8×10^{-6}	7.1×10^{-10}	1.5×10^{-8}	7.7×10^{-12}	3.3×10^{-5}	1.7×10^{-8}	1.0×10^{-4}
Leaks or spills from breach of containment	6.3×10^{-10}	2.5×10^{-13}	5.5×10^{-12}	2.7×10^{-15}	1.2×10^{-10}	5.9×10^{-12}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	3.7×10^{-4}	1.5×10^{-7}	3.2×10^{-6}	1.6×10^{-9}	6.9×10^{-3}	3.5×10^{-6}	1.0×10^{-4}
Nuclear criticality	5.0×10^{-4}	2.0×10^{-7}	3.9×10^{-6}	1.9×10^{-9}	8.5×10^{-4}	4.3×10^{-7}	1.0×10^{-7}
Beyond evaluation basis fire	0.013	5.1×10^{-6}	1.1×10^{-4}	5.5×10^{-8}	0.24	1.2×10^{-4}	1.0×10^{-7}
Beyond evaluation basis explosion	18.6	9.2×10^{-3}	0.16	8.0×10^{-5}	346	0.17	1.0×10^{-7}
Beyond evaluation basis earthquake	9.3	3.7×10^{-3}	0.080	4.0×10^{-5}	173	0.086	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

Table M.5.3.2.2–4. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Pantex Plant

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.13	5.1×10^{-5}	0.041	2.0×10^{-5}	6.3	3.2×10^{-3}	5.0×10^{-4}
Evaluation basis fire in process cell	7.7×10^{-7}	3.1×10^{-10}	2.4×10^{-7}	1.2×10^{-10}	3.8×10^{-5}	1.9×10^{-8}	1.0×10^{-4}
Leaks or spills from breach of containment	2.7×10^{-10}	1.1×10^{-13}	8.7×10^{-11}	4.3×10^{-14}	1.3×10^{-8}	6.7×10^{-12}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	1.6×10^{-4}	6.4×10^{-8}	5.1×10^{-5}	2.6×10^{-8}	7.9×10^{-3}	3.9×10^{-6}	1.0×10^{-4}
Nuclear criticality	2.4×10^{-4}	9.7×10^{-8}	9.3×10^{-5}	4.6×10^{-8}	2.3×10^{-3}	1.1×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire	5.5×10^{-3}	2.2×10^{-6}	1.7×10^{-3}	8.7×10^{-7}	0.27	1.3×10^{-4}	1.0×10^{-7}
Beyond evaluation basis explosion	8.0	3.3×10^{-3}	2.6	1.3×10^{-3}	393	0.20	1.0×10^{-7}
Beyond evaluation basis earthquake	4.0	1.6×10^{-3}	1.3	6.4×10^{-4}	196	9.8×10^{-2}	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

Table M.5.3.2.2–5. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Oak Ridge Reservation

	Worker at 801[a]m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.36	1.4×10^{-4}	0.36	1.8×10^{-4}	74	0.037	5.0×10^{-4}
Evaluation basis fire in process cell	2.2×10^{-6}	8.7×10^{-10}	2.2×10^{-6}	1.1×10^{-9}	4.4×10^{-4}	2.2×10^{-7}	1.0×10^{-4}
Leaks or spills from breach of containment	7.7×10^{-10}	3.1×10^{-13}	7.7×10^{-10}	3.8×10^{-13}	1.6×10^{-7}	7.9×10^{-1}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	4.5×10^{-4}	1.8×10^{-7}	4.5×10^{-4}	2.3×10^{-7}	0.092	4.6×10^{-5}	1.0×10^{-4}
Nuclear criticality	5.8×10^{-4}	2.3×10^{-7}	5.8×10^{-4}	2.9×10^{-7}	0.040	2.0×10^{-5}	1.0×10^{-7}
Beyond evaluation basis fire	0.015	6.2×10^{-6}	0.015	7.7×10^{-6}	3.2	1.6×10^{-3}	1.0×10^{-7}
Beyond evaluation basis explosion	22.6	0.011	22.6	0.013	4,620	2.3	1.0×10^{-7}
Beyond evaluation basis earthquake	11.3	4.5×10^{-3}	11.3	5.6×10^{-3}	2,310	1.2	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary [801 m for this facility at ORR], whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

Table M.5.3.2.2–6. Mixed Oxide Fuel Fabrication Facility Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Evaluation basis fire on open loading dock	0.21	8.4×10^{-5}	5.9×10^{-3}	2.9×10^{-6}	19.8	9.9×10^{-3}	5.0×10^{-4}
Evaluation basis fire in process cell	1.3×10^{-6}	5.0×10^{-10}	3.5×10^{-8}	1.8×10^{-11}	1.2×10^{-4}	5.9×10^{-8}	1.0×10^{-4}
Leaks or spills from breach of containment	4.4×10^{-10}	1.8×10^{-13}	1.2×10^{-11}	6.2×10^{-15}	4.2×10^{-8}	2.1×10^{-11}	4.5×10^{-5}
Evaluation basis explosion inside a glovebox	2.6×10^{-4}	1.0×10^{-7}	7.3×10^{-6}	3.7×10^{-9}	0.025	1.2×10^{-5}	1.0×10^{-4}
Nuclear criticality	3.5×10^{-4}	1.4×10^{-7}	9.0×10^{-6}	4.5×10^{-9}	4.6×10^{-3}	2.3×10^{-6}	1.0×10^{-7}
Beyond evaluation basis fire	8.9×10^{-3}	3.6×10^{-6}	2.5×10^{-4}	1.2×10^{-7}	0.84	4.2×10^{-4}	1.0×10^{-7}
Beyond evaluation basis explosion	13.0	5.8×10^{-3}	0.36	1.8×10^{-4}	1,240	0.62	1.0×10^{-7}
Beyond evaluation basis earthquake	6.5	2.8×10^{-3}	0.18	9.1×10^{-5}	618	0.31	1.0×10^{-7}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source term in Tables M.5.3.2.1–4 and M.5.3.2.1–5 and the MACCS computer code.

M.5.3.3 Direct Disposition Alternative for a Deep Borehole Complex

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a deep borehole disposal facility and the direct emplacement of Pu and Plutonium Dioxide in the *Fissile Material Disposition Program Deep Borehole Disposal Facility PEIS Data Input Report for Direct Disposal–Direct Disposal of Plutonium/Plutonium Dioxide in Compound Canisters.* The studies postulated a set of accident scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risks that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than 1.0×10^{-7}/yr are anticipated that will have consequences and risks larger than those described in this section.

M.5.3.3.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, seven evaluation basis accidents with release to the environment and three beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.3.1–1 and M.5.3.3.1–2. Accident source term information is provided in Tables M.5.3.3.1–3 and M.5.3.3.1–4. Descriptions of accident scenarios are provided in Table M.5.3.3.1–5.

Table M.5.3.3.1–1. Evaluation Basis Accident Scenarios for Direct Disposition at the Deep Borehole Complex

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Evaluation basis earthquake	$1.0x10^{-6}$ to $1.0x10^{-4}$	NA	No release
Evaluation basis tornado	$1.0x10^{-6}$ to $1.0x10^{-4}$	NA	No release
Evaluation basis flood	$1.0x10^{-6}$ to $1.0x10^{-4}$	NA	No release
Pu storage container breakage during storage	$1.0x10^{-4}$ to 0.01	4.5 kg Pu	$4.5x10^{-10}$ g Pu
Pu storage container breakage during handling	$1.0x10^{-4}$ to 0.01	4.5 kg Pu	$4.5x10^{-8}$ g Pu
Emplacement canister dropped during handling	$1.0x10^{-4}$ to 0.01	40.5 kg Pu	No release
Onsite emplacement canister transportation accident	$1.0x10^{-4}$ to 0.01	40.5 kg Pu	No release
Nuclear Criticality during emplacement canister filling	$1.0x10^{-6}$ to $1.0x10^{-4}$	$1.0x10^{19}$ prompt fissions in 8 hrs; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]
Nuclear Criticality during Pu storage container spill	$1.0x10^{-6}$ to $1.0x10^{-4}$	$1.0x10^{19}$ prompt fissions in 8 hrs; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]
Fire in facility process areas	$1.0x10^{-6}$ to $1.0x10^{-4}$	40.5 kg Pu	$4.05x10^{-5}$ g Pu
Failure of ventilation filter	0.01 to 0.1	NA	No release
Failure of ventilation blower	0.5	NA	No release
Loss of electrical power	1.0	NA	No release
Canister string dropped during emplacement—ruptured in emplacement zone	$1.0x10^{-6}$ to $1.0x10^{-4}$	1,012 kg Pu	$4.05x10^{-4}$ g Pu
Canister string dropped during emplacement—ruptured and stuck in isolation zone	$1.0x10^{-6}$ to $1.0x10^{-4}$	1,012 kg Pu	$2.43x10^{-7}$ g Pu
Canister string struck in emplacement zone	$1.0x10^{-6}$ to $1.0x10^{-4}$	1,012 kg Pu	No release
Canister string struck in isolation zone	$1.0x10^{-6}$ to $1.0x10^{-4}$	1,012 kg Pu	No release
Emplacement facility fire - electrical	$1.0x10^{-6}$ to $1.0x10^{-4}$	1,012 kg Pu	No release

[a] See Table M.5.3.3.1–3.

Note: NA=not applicable.

Source: LLNL 1996a.

Table M.5.3.3.1–2. Beyond Evaluation Basis Accident Scenarios for Direct Disposition at the Deep Borehole Complex

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Uncontrolled chemical reaction	$<1.0 \times 10^{-6}$	NA	No release
Pu container nuclear criticality in storage	$<1.0 \times 10^{-6}$	1.0×10^{19} prompt fissions in 8 hr; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]
Emplacement canister nuclear criticality in storage	$<1.0 \times 10^{-6}$	1.0×10^{19} prompt fissions in 8 hr; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]
Nuclear criticality of canister contents at bottom of emplacement zone upon rupture of dropped canister string	$<1.0 \times 10^{-6}$	1.0×10^{19} prompt fissions in 8 hr; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]

[a] See Table M.5.3.3.1–4.

Note: NA=not applicable.

Source: LLNL 1996a.

Table M.5.3.3.1–3. Direct Disposition at the Deep Borehole Complex Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario						
	Pu Storage Container Breakage During Storage	Pu Storage Container Breakage During Handling	Nuclear Criticality During Emplacement Canister Filling[a]	Nuclear Criticality During Pu Storage Container Spill[b]	Fire in Facility Process Area	Canister String Dropped During Emplacement—Ruptured in Emplacement Zone	Canister String Dropped During Emplacement—Ruptured and Stuck in Isolation Zone
Frequency of occurrence[b] (per year)	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}
Pu released to environment (g)	4.5×10^{-10}	4.5×10^{-8}	–	–	4.05×10^{-5}	4.05×10^{-4}	2.43×10^{-7}
Fissions	–	–	1.0×10^{19}	1.0×10^{19}	–	–	–
Isotope Released to Environment (Ci)							
Pu-238	7.11×10^{-13}	7.11×10^{-11}	0	0	6.40×10^{-8}	6.40×10^{-7}	3.84×10^{-10}
Pu-239	2.57×10^{-11}	2.57×10^{-9}	0	0	2.32×10^{-6}	2.32×10^{-5}	1.39×10^{-8}
Pu-240	6.84×10^{-12}	6.84×10^{-10}	0	0	6.16×10^{-7}	6.16×10^{-6}	3.69×10^{-9}
Pu-241	2.43×10^{-11}	2.43×10^{-9}	0	0	2.18×10^{-6}	2.18×10^{-5}	1.31×10^{-8}
Pu-242	1.00×10^{-15}	1.00×10^{-13}	0	0	9.03×10^{-11}	9.03×10^{-10}	5.42×10^{-13}
Am-241	1.28×10^{-13}	1.28×10^{-11}	0	0	1.15×10^{-8}	1.15×10^{-7}	6.90×10^{-11}
Kr-83m	0	0	110	110	0	0	0
Kr-85m	0	0	71	71	0	0	0
Kr-85	0	0	8.1×10^{-4}	8.1×10^{-4}	0	0	0
Kr-87	0	0	430	430	0	0	0
Kr-88	0	0	230	230	0	0	0
Kr-89	0	0	1.3×10^{-4}	1.3×10^{-4}	0	0	0
Xe-131m	0	0	0.1	0.1	0	0	0
Xe-133m	0	0	2.2	2.2	0	0	0
Xe-133	0	0	27	27	0	0	0
Xe-135m	0	0	3.3×10^{3}	3.3×10^{3}	0	0	0
Xe-135	0	0	410	410	0	0	0
Xe-137	0	0	4.9×10^{4}	4.9×10^{4}	0	0	0
Xe-138	0	0	1.1×10^{4}	1.1×10^{4}	0	0	0
I-131	0	0	2.75	2.75	0	0	0
I-132	0	0	300	300	0	0	0
I-133	0	0	40	40	0	0	0
I-134	0	0	1.08×10^{3}	1.08×10^{3}	0	0	0
I-135	0	0	113	113	0	0	0

[a] Curies produced (by isotope) for the 1.0×10^{19} fission criticality were scaled from Table M.5.3.1.1–3.

[b] Midpoint of the estimated frequency range.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.3.1–1.

Table M.5.3.3.1–4. Direct Disposition at the Deep Borehole Complex Beyond Evaluation Basis Accident Source Terms

	Accident Scenario		
Accident Parameter	**Pu Container Nuclear Criticality in Storage[a]**	**Emplacement Canister Nuclear Criticality in Storage[a]**	**Nuclear Criticality of Canister Contents at Bottom of Emplacement Zone Upon Rupture of Dropped Canister String[a]**
Frequency of occurrence (per year)	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Pu released to environment	NA	NA	NA
Fissions	1.0×10^{19}	1.0×10^{19}	1.0×10^{19}
Isotope Released to Environment (Ci)			
[Text deleted.]			
Kr-83m	110	110	110
Kr-85m	71	71	71
Kr-85	8.1×10^{-4}	8.1×10^{-4}	8.1×10^{-4}
Kr-87	430	430	430
Kr-88	230	230	230
Kr-89	1.3×10^{-4}	1.3×10^{-4}	1.3×10^{-4}
Xe-131m	0.1	0.1	0.1
Xe-133m	2.2	2.2	2.2
Xe-133	27	27	27
Xe-135m	3.3×10^{3}	3.3×10^{3}	3.3×10^{3}
Xe-135	410	410	410
Xe-137	4.9×10^{4}	4.9×10^{4}	4.9×10^{4}
Xe-138	1.1×10^{4}	1.1×10^{4}	1.1×10^{4}
I-131	2.75	2.75	2.75
I-132	300	300	300
I-133	40	40	40
I-134	1.08×10^{3}	1.08×10^{3}	1.08×10^{3}
I-135	113	113	113

[a] Curies produced (by isotope) for the 1.0×10^{19} fission criticality were scaled from Table M.5.3.1.1–3.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.3.1–2.

Table M.5.3.3.1–5. Accident Scenario Descriptions for Direct Disposition at the Deep Borehole Complex

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Pu storage container breakage during storage	It is postulated that a Pu storage container is ruptured due to overpressurization of the container. The overpressurization could occur as a result of volume expansion caused by either complete oxidation of Pu metal buttons stored in cans or pressure buildup due to radiolysis of residual moisture in Pu oxide and helium gas from the alpha decay of Pu and daughter products. Respirable Pu fines are released to the storage area.
Pu storage container breakage during handling	It is postulated that a 2R Pu container is dropped and breaches in container handling operations. The force of the drop ruptures the container and respirable oxide fines are released to the process area.
Nuclear criticality during emplacement canister filling	Mishandling of the Pu containers during handling operations could lead to a criticality accident. At least three independent and concurrent equipment failures or operation errors must occur before a criticality accident could occur. It is postulated that additional Pu containers are introduced into the emplacement canister filling process area in violation of procedural controls and a criticality occurs as a result of the containers being spaced too closely.
Nuclear criticality during Pu storage canister spill	A nuclear criticality could occur if Pu containers were damaged in handling and the mass of the spilled Pu oxide containers exceeds the critical mass. Because each 2R primary container contains a limited amount of Pu, a criticality accident would require successively damaging several containers.
Fire in process area	The combustible loading in the process area is very low because the process does not involve any combustible materials. However, it is postulated that a large fire occurs in the process area for emplacement canister filling, the containers are breached by the fire, and the contents are exposed to the fire. The ventilation system two-stage HEPA filters are operational during the fire.
Canister string dropped during emplacement, ruptured in emplacement zone	A canister string could be dropped into the borehole as a result of either a structural failure in the crane and associated hoisting and securing equipment or as a result of operator error. A free-falling canister string could rupture upon impact at the bottom of the borehole.
Canister string dropped during emplacement, ruptured and stuck in isolation zone	A canister string could be dropped into the borehole as a result of either a structural failure in the crane and associated hoisting and securing equipment or as a result of operator error. The canister string impacts a projecting ledge at a change in the diameter of the well casings, ruptures, and remains stuck in the isolation zone instead of falling to the bottom of the borehole.
Beyond Evaluation Basis Accidents	
Pu container nuclear criticality in storage	The Pu storage facility is designed to ensure that an accidental criticality during dry or flood conditions is not credible. The assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.
Emplacement canister nuclear criticality in storage	The storage racks are designed to maintain the geometry of the array under all postulated accident and natural conditions. The assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.
Nuclear criticality of canister contents at bottom of emplacement zone upon rupture of dropped canister string	A canister string could be dropped into the borehole as a result of either a structural failure in the crane and associated hoisting and securing equipment or as a result of operator error. A free-falling canister string could rupture upon impact at the bottom of the borehole. The evaluation assumed that Pu released from the ruptured string would collect in a critical mass at the bottom of the borehole. The assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.

Source: LLNL 1996a.

M.5.3.3.2 *Accident Impacts*

The estimated range of impacts of the postulated accidents at reference sites is provided in Table M.5.3.3.2–1. The estimated range of environmental data (wet to dry site) and the general public population density data (low to high density) for the reference sites envelope the site characteristics expected for the direct disposition site. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.3.1–3 and M.5.3.3.1–4 using the MACCS computer code. [Text deleted.]

[Text deleted.]

Table M.5.3.3.2–1. Direct Disposition at the Deep Borehole Complex Accident Impacts Ranges at Generic Sites

	Worker at 1,000 m				Maximum Offsite Individual				Population to 80 km				
	Dose (rem)		Probability of Cancer Fatality[a]		Dose (rem)		Probability of Cancer Fatality[a]		Dose (person-rem)		Number of Cancer Fatalities[b]		Accident Frequency (per year)
Accident Scenario	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	
Pu storage container breakage during storage	1.3×10^{-10}	5.3×10^{-11}	5.1×10^{-14}	2.1×10^{-14}	2.1×10^{-11}	9.4×10^{-13}	1.0×10^{-14}	4.7×10^{-16}	1.8×10^{-8}	1.7×10^{-10}	9×10^{-12}	8.4×10^{-14}	1.0×10^{-3}
Pu storage container breakage during handling	1.3×10^{-8}	5.3×10^{-9}	5.1×10^{-12}	2.1×10^{-12}	2.1×10^{-9}	9.4×10^{-11}	1.0×10^{-12}	4.7×10^{-14}	1.8×10^{-6}	1.7×10^{-8}	9.0×10^{-10}	8.4×10^{-12}	1.0×10^{-3}
Nuclear criticality during emplacement canister filling	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	4.6×10^{-2}	6.3×10^{-4}	2.3×10^{-5}	1.0×10^{-5}
Nuclear criticality during Pu storage canister spill	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.2	6.6×10^{-3}	6.0×10^{-4}	3.3×10^{-6}	1.0×10^{-5}
Fire in process area	1.2×10^{-5}	4.7×10^{-6}	4.6×10^{-9}	1.9×10^{-9}	1.9×10^{-6}	8.4×10^{-8}	9.3×10^{-10}	4.2×10^{-11}	1.6×10^{-3}	6.6×10^{-3}	8.1×10^{-7}	3.3×10^{-6}	1.0×10^{-5}
Canister string dropped during emplacement, ruptured in emplacement zone	1.2×10^{-4}	4.7×10^{-5}	4.6×10^{-8}	1.9×10^{-8}	1.9×10^{-5}	8.5×10^{-7}	9.3×10^{-9}	4.2×10^{-12}	1.6×10^{-2}	1.5×10^{-4}	8.1×10^{-6}	7.6×10^{-8}	1.0×10^{-5}
Canister string dropped during emplacement, ruptured in isolation zone	6.9×10^{-8}	2.8×10^{-8}	2.8×10^{-11}	1.1×10^{-11}	1.1×10^{-8}	5.0×10^{-10}	5.6×10^{-12}	2.5×10^{-13}	9.7×10^{-6}	9.0×10^{-8}	4.9×10^{-9}	4.5×10^{-11}	1.0×10^{-5}
Pu container nuclear criticality in storage	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	6.6×10^{-3}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}
Emplacement canister nuclear criticality in storage	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	6.6×10^{-3}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}
Nuclear criticality of canister contents at bottom of emplacement zone upon rupture of dropped canister string	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	6.6×10^{-3}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Source: Calculated using the source terms in Tables M.5.3.3.1–3 and M.5.3.3.1–4 and the MACCS computer code.

M.5.3.4 Immobilized Disposition Alternative for a Deep Borehole Complex

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a deep borehole immobilized disposal facility in the *Fissile Material Disposition Program: Deep Borehole Disposal Facility PEIS Data Input Report for Immobilized Disposal—Immobilized Disposal of Plutonium in Coated Ceramic Pellets in Grout Without Canisters*. The studies postulated a set of accidents scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risk that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than 1.0×10^{-7}/yr are anticipated that will have consequences and risks larger than those described in this section.

M.5.3.4.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, 14 evaluation basis accidents and 4 beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.4.1–1 and M.5.3.4.1–2. Accident source term information is provided in Tables M.5.3.4.1–3 and M.5.3.4.1–4. Descriptions of accident scenarios are provided in Table M.5.3.4.1–5.

Table M.5.3.4.1–1. Evaluation Basis Accident Scenarios for Immobilized Disposition at the Deep Borehole Complex

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Earthquake	1.0×10^{-6} to 1.0×10^{-4}	5 kg Pu	5.0×10^{-10} g Pu
Tornado	1.0×10^{-6} to 1.0×10^{-4}	NA	No release
Flood	1.0×10^{-6} to 1.0×10^{-4}	NA	No release
Pu storage container breakage	1.0×10^{-4} to 0.01	5 kg Pu	5.0×10^{-12} g Pu
Pu storage container breach	1.0×10^{-4} to 0.01	5 kg Pu	5.0×10^{-12} g Pu
Onsite pellet transporter accident	1.0×10^{-4} to 0.01	5 kg Pu	No release
Pellet-grout mixing process facility fire	1.0×10^{-6} to 1.0×10^{-4}	5 kg Pu	5.0×10^{-10} g Pu
Ceramic pellet spill	1.0×10^{-4} to 0.01	0.5 kg Pu	5.0×10^{-13} g Pu
Pellet-grout mix spill	0.01 to 0.1	0.5 kg Pu	3.0×10^{-11} g Pu
Failure of ventilation blower	0.01 to 0.1	NA	No release
Loss of electrical power	0.01 to 0.1	NA	No release
Bucket Emplacement			
Bucket dropped during emplacement	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	5.0×10^{-7} g Pu
Bucket stuck in the isolation zone	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Bucket stuck in emplacement zone	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Failure of release—fails to open	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Failure of release—opens early during bucket emplacement	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	2.5×10^{-6} g Pu
Pellet-grout sets in bucket	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Mixing system breaks pellets during bucket emplacement	1.0×10^{-4} to 0.01	834 kg Pu	5.0×10^{-8} g Pu
Pellets break during bucket emplacement release	1.0×10^{-4} to 0.01	834 kg Pu	5.0×10^{-8} g Pu
Emplacement facility fire - combustibles	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Emplacement facility fire - electrical	1.0×10^{-6} to 1.0×10^{-4}	834 kg Pu	No release
Loss of electrical power	0.01 to 0.1	NA	No release
Pumped Emplacement			
Rupture of delivery pipe during pumped emplacement	1.0×10^{-6} to 1.0×10^{-4}	100 kg Pu	3.0×10^{-7} g Pu
Pellet-grout solidifies in delivery pipe	1.0×10^{-4} to 0.01	100 kg Pu	No release
Delivery pipe dropped during pumped emplacement	1.0×10^{-6} to 1.0×10^{-4}	100 kg Pu	6.0×10^{-8} g Pu
Delivery pipe stuck in the borehole	$<1.0\times10^{-6}$	100 kg Pu	No release
Mixing system breaks pellets during pumped emplacement	1.0×10^{-4} to 0.01	100 kg Pu	6.0×10^{-9} g Pu
Pellets break during release during pumped emplacement	1.0×10^{-4} to 0.01	100 kg Pu	6.0×10^{-9} g Pu

Table M.5.3.4.1–1. Evaluation Basis Accident Scenarios for Immobilized Disposition at the Deep Borehole Complex—Continued

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Emplacement facility fire—combustibles	$1.0x10^{-6}$ to $1.0x10^{-4}$	100 kg Pu	No release
Emplacement facility fire—electrical	$1.0x10^{-6}$ to $1.0x10^{-4}$	100 kg Pu	No release
Loss of electrical power	0.01 to 0.1	NA	No release

Note: NA=not applicable.

Source: LLNL 1996h.

Table M.5.3.4.1–2. Beyond Evaluation Basis Accident Scenarios for Immobilized Disposition at the Deep Borehole Complex

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Failure of ventilation filter	$<1.0x10^{-6}$	0.5 kg Pu	$3.0x10^{-9}$ g Pu
Uncontrolled chemical reaction	$<1.0x10^{-6}$	5 kg Pu	$5.0x10^{-9}$ g Pu
Pellet storage nuclear criticality	$<1.0x10^{-6}$	$1.0x10^{19}$ prompt fissions in 8 hrs; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen	[a]
Pellet-grout mixing nuclear criticality	$<1.0x10^{-6}$	$1.0x10^{19}$ prompt fissions in 8 hrs; noble gas and halogen fission products release. Release factors: 1.0 noble gas, 0.25 halogen.	[a]

[a] See Table M.5.3.4.1–4.

Source: LLNL 1996h.

Table M.5.3.4.1–3. Immobilized Disposition at the Deep Borehole Complex Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario						
	Earthquake	Pu Storage Container Breakage	Pu Storage Container Breach	Pellet-Grout Mixing Process Facility Fire	Ceramic Pellet Spill	Pellet-Grout Mix Spill	Dropped Bucket During Emplacement
Frequency of occurrence (per year)	1.0×10^{-5}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-5}	1.0×10^{-3}	0.05	1.0×10^{-5}
Pu released to environment (g)	5.0×10^{-10}	5.0×10^{-12}	5.0×10^{-12}	5.0×10^{-10}	5.0×10^{-13}	3.0×10^{-11}	5.0×10^{-7}
Isotope Released to Environment (Ci)							
Pu-238	7.90×10^{-13}	7.90×10^{-15}	7.90×10^{-15}	7.90×10^{-13}	7.90×10^{-16}	4.74×10^{-14}	7.90×10^{-10}
Pu-239	2.86×10^{-11}	2.86×10^{-13}	2.86×10^{-13}	2.86×10^{-11}	2.86×10^{-14}	1.72×10^{-12}	2.86×10^{-8}
Pu-240	7.60×10^{-12}	7.60×10^{-14}	7.60×10^{-14}	7.60×10^{-12}	7.60×10^{-15}	4.56×10^{-13}	7.60×10^{-9}
Pu-241	2.69×10^{-11}	2.69×10^{-13}	2.69×10^{-13}	2.69×10^{-11}	2.69×10^{-14}	1.62×10^{-12}	2.69×10^{-8}
Pu-242	1.11×10^{-15}	1.12×10^{-17}	1.12×10^{-17}	1.11×10^{-15}	1.12×10^{-18}	6.69×10^{-17}	1.12×10^{-12}
Am-241	1.42×10^{-13}	1.42×10^{-15}	1.42×10^{-15}	1.42×10^{-13}	1.42×10^{-16}	8.52×10^{-15}	1.42×10^{-10}

Table M.5.3.4.1–3. Immobilized Disposition at the Deep Borehole Complex Evaluation Basis Accident Source Terms—Continued

Accident Parameter	Accident Scenario						
	Failure of Release - Opens Early During Bucket Emplacement	Mixing System Breaks Pellets During Bucket Emplacement	Pellets Break During Bucket Emplacement Release	Rupture of Delivery Pipe During Pumped Emplacement	Delivery Pipe Dropped During Pumped Emplacement	Mixing System Breaks Pellets During Pumped Emplacement	Pellets Break During Pumped Emplacement Release
Frequency of occurrence[a](per year)	1.0×10^{-5}	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-3}	1.0×10^{-3}
Pu released to environment (g)	2.5×10^{-6}	5.0×10^{-8}	5.0×10^{-8}	3.0×10^{-7}	6.0×10^{-8}	6.0×10^{-9}	6.0×10^{-9}
Isotope Released to Environment (Ci)							
Pu-238	3.95×10^{-9}	7.90×10^{-11}	7.90×10^{-11}	4.74×10^{-10}	9.48×10^{-11}	9.48×10^{-12}	9.48×10^{-12}
Pu-239	1.43×10^{-7}	2.86×10^{-9}	2.86×10^{-9}	1.72×10^{-8}	3.43×10^{-9}	3.43×10^{-10}	3.43×10^{-10}
Pu-240	3.80×10^{-8}	7.60×10^{-10}	7.60×10^{-10}	4.56×10^{-9}	9.12×10^{-10}	9.12×10^{-11}	9.12×10^{-11}
Pu-241	1.35×10^{-7}	2.70×10^{-9}	2.70×10^{-9}	1.62×10^{-8}	3.23×10^{-9}	3.23×10^{-10}	3.23×10^{-10}
Pu-242	5.58×10^{-12}	1.12×10^{-13}	1.12×10^{-13}	6.69×10^{-13}	1.34×10^{-13}	1.34×10^{-14}	1.34×10^{-15}
Am-241	7.10×10^{-10}	1.42×10^{-11}	1.42×10^{-11}	8.52×10^{-11}	1.70×10^{-11}	1.70×10^{-12}	1.70×10^{-12}

[a]Midpoint of the estimated frequency range.

Note: Am=Americium.

Source: Derived from Tables M.5.1.3.4–1 and M.5.3.4.1–1.

Table M.5.3.4.1–4. Immobilized Disposition at the Deep Borehole Complex Beyond Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario			
	Failure of Ventilation Filter	Uncontrolled Chemical Reaction	Pellet Storage Nuclear Criticality[a]	Pellet-Grout Mixing Process Nuclear Criticality
Frequency of occurrence (per year)	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Pu released to environment (g)	3.0×10^{-9}	5.0×10^{-9}	NA	NA
Fissions	NA	NA	1.0×10^{19}	1.0×10^{19}
Isotope Released to Environment (Ci)				
Pu-238	4.74×10^{-12}	7.90×10^{-12}	0	0
Pu-239	1.72×10^{-10}	2.86×10^{-10}	0	0
Pu-240	4.56×10^{-11}	7.60×10^{-11}	0	0
Pu-241	1.62×10^{-10}	2.70×10^{-10}	0	0
Pu-242	6.69×10^{-15}	1.12×10^{-14}	0	0
Am-241	8.52×10^{-13}	1.42×10^{-12}	0	0
Kr-83m	0	0	110	110
Kr-85m	0	0	71	71
Kr-85	0	0	8.1×10^{-4}	8.1×10^{-4}
Kr-87	0	0	430	430
Kr-88	0	0	230	230
Kr-89	0	0	1.3×10^{-4}	1.3×10^{-4}
Xe-131m	0	0	0.1	0.1
Xe-133m	0	0	2.2	2.2
Xe-133	0	0	27	27
Xe-135m	0	0	3.3×10^{3}	3.3×10^{3}
Xe-135	0	0	410	410
Xe-137	0	0	4.9×10^{4}	4.9×10^{4}
Xe-138	0	0	1.1×10^{4}	1.1×10^{4}
I-131	0	0	2.75	2.75
I-132	0	0	300	300
I-133	0	0	40	40
I-134	0	0	1.08×10^{3}	1.08×10^{3}
I-135	0	0	113	113

[a] Curies produced (by isotope) for the 1.0×10^{19} fission criticality were scaled from Table M.5.3.1.1–3.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.4.1–2.

Table M.5.3.4.1–5. Accident Scenario Descriptions for Immobilized Disposition at the Deep Borehole Complex

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Earthquake	It was postulated that the evaluation basis earthquake would rupture the ceramic pellet grouting vessel and lines. The Pu-containing particulate would be removed from the grouting area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Pu storage container breakage	It is postulated that a container breakage could occur in ceramic pellet storage. Respirable fines of ceramic are released to the storage area and collected by the ventilation system. The airborne fines pass through the ventilation HEPA filters and are released to the environment.
Pu storage container breach	It is postulated that a container breach could occur in ceramic pellet container handling operations. A container is punctured during handling and ceramic pellets spill from the punctured container. Respirable fines of ceramic are released to the process area and collected by the ventilation system. The airborne fines pass through the ventilation HEPA filters and are released to the environment.
Pellet-grout mixing process facility fire	It is postulated that an unimpeded fire begins in the process area which houses the grouting vessel. The fire breaches the vessel enclosure that contains the Pu-loaded ceramic pellets. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Ceramic pellet spill	It is postulated that the ceramic pellets overflow the grouting feed bin and spill onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in two hours but some of the spill material converts to an aerosol and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Pellet-grout mix spill	It is postulated that the grouting vessel or the bucket overflows and spills onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in 2 hours but some of the spill material converts to an aerosol and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Dropped bucket during emplacement	A bucket could be dropped into the borehole as a result of either a structural failure in the crane, the associated hoisting and securing equipment, or as a result of operator error. A free-falling bucket could rupture upon impact at the bottom of the borehole.
Failure of release—opens early during bucket emplacement	The valve at the bottom of the bucket opens prematurely and the pellets and the cement free fall to the bottom of the borehole. This would probably result in some broken or fractured pellets.
Mixing system breaks pellets during emplacement	The pellets are mixed with cement and pushed with water, air pressure, or gravity into the bucket. It is postulated that some of the pellets may break or crack due to unforeseen events in the emplacement process.
Pellets break during bucket emplacement release	Upon release, the pellets and cement will flow out into the borehole. The weight of the column in the bucket and the pressure that will likely be needed to push out the mix could cause some of the pellets to break due to some unforeseen events in the emplacement process.
Rupture of delivery pipe during pumped emplacement	If the delivery pipe were to rupture, the pellets and cement would free fall to the bottom of the borehole. This would probably result in some broken or fractured pellets.

Table M.5.3.4.1–5. Accident Scenario Descriptions for Immobilized Disposition at the Deep Borehole Complex—Continued

Accident Scenario	Accident Description
Delivery pipe dropped during pumped emplacement	A delivery pipe could be dropped into the borehole as a result of either a structural failure in the crane or drill rig, or as a result to operator error. Substantial quantities of ceramic pellets could be broken or cracked upon impact at the bottom of the borehole.
Mixing system breaks pellets during pumped emplacement	The pellets are mixed with cement and pushed with water, air pressure, or gravity into the delivery pipe. It is postulated that some of the pellets may break or crack due to unforeseen events in the process.
Pellets break during pumped emplacement release	Upon release from the end of the delivery pipe, the pellets and cement will flow out into the borehole. The weight of the column in the pipe and the pressure that will likely be needed to push out the mix could cause some of the pellets to break due to some unforeseen events in the emplacement process.
Beyond Evaluation Basis Accidents	
Failure of ventilation filter	A HEPA filter could fail due to moisture collection on the filter, excessive pressure loading from exhaust blower, excessive heat from a fire, or mechanical shock. It is postulated that the HEPA filter servicing the grout mixing process fails concurrently with a grouting process spill accident. Some of the spill material converts to an aerosol and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system, pass through the failed HEPA filters and be released to the environment.
Uncontrolled chemical reaction	It is postulated that hydrogen produced in the battery of the uninterruptible power system detonates in the grout mix vessel area, fractures pellets in the process, and some of the fractured pellets becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Pellet storage nuclear criticality	The designed Pu concentration in the ceramic pellet is sufficiently low to maintain criticality safe under all postulated accidents and natural conditions. The facility is designed to preclude flooding in the storage area. A nuclear criticality accident in the pellet storage vault area is not credible. However, a criticality accident was postulated, and the assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.
Pellet-grout mixing process nuclear criticality	The designed Pu concentration in the ceramic pellet is sufficiently low to maintain criticality safe under all postulated accidents during grout mixing process conditions. A nuclear criticality accident in the pellet storage vault area is not credible. However, a criticality accident was postulated, and the assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.

Source: LLNL 1996a.

M.5.3.4.2 *Accident Impacts*

The estimated range of impacts of the postulated accidents at reference sites are provided in Table M.5.3.4.2–1. The estimated range of environmental data (wet to dry site) and the general public population density data (low to high density) for the reference sites envelop the site characteristics expected for the emplacement site. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.4.1–3 and M.5.3.4.1–4 using the MACCS computer code.

[Text deleted.]

Table M.5.3.4.2–1. Immobilized Disposition at the Deep Borehole Complex Accident Impacts Ranges at Generic Site

	Worker at 1,000 m				Maximum Offsite Individual				Population to 80 km				
	Dose (rem)		Probability of Cancer Fatality[a]		Dose (rem)		Probability of Cancer Fatality[a]		Dose (person-rem)		Number of Cancer Fatalities[b]		Accident Frequency (per year)
Accident Scenario	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	
Earthquake	1.4×10^{-10}	5.8×10^{-11}	5.7×10^{-14}	2.3×10^{-14}	2.3×10^{-11}	1.0×10^{-12}	1.2×10^{-14}	$5./2\times10^{-16}$	2.0×10^{-8}	1.9×10^{-10}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-5}
Pu storage container breakage	1.4×10^{-12}	5.8×10^{-13}	5.7×10^{-16}	2.3×10^{-16}	2.3×10^{-13}	1.0×10^{-14}	1.2×10^{-16}	5.2×10^{-18}	2.0×10^{-10}	1.9×10^{-12}	1.0×10^{-13}	9.3×10^{-16}	1.0×10^{-3}
Pu storage container breach	1.4×10^{-12}	5.8×10^{-13}	5.7×10^{-16}	2.3×10^{-16}	2.3×10^{-13}	1.0×10^{-14}	1.2×10^{-16}	5.2×10^{-18}	2.0×10^{-10}	1.9×10^{-12}	1.0×10^{-13}	9.3×10^{-16}	1.0×10^{-3}
Pellet-grout mixing process facility fire	1.4×10^{-10}	5.8×10^{-11}	5.7×10^{-14}	2.3×10^{-14}	2.3×10^{-11}	1.0×10^{-12}	1.2×10^{-14}	5.2×10^{-16}	2.0×10^{-8}	1.9×10^{-10}	1.0×10^{-11}	9.3×10^{-14}	1.0×10^{-5}
Ceramic pellet spill	1.4×10^{-13}	5.8×10^{-14}	5.7×10^{-17}	2.3×10^{-17}	2.3×10^{-14}	1.0×10^{-15}	1.2×10^{-17}	5.2×10^{-19}	2.0×10^{-11}	1.9×10^{-13}	1.0×10^{-14}	9.3×10^{-17}	1.0×10^{-3}
Pellet grout mix spill	8.5×10^{-12}	3.4×10^{-12}	3.4×10^{-15}	1.4×10^{-15}	1.4×10^{-12}	6.2×10^{-14}	6.9×10^{-16}	3.1×10^{-17}	1.2×10^{-9}	1.1×10^{-11}	6.0×10^{-13}	5.5×10^{-15}	5.0×10^{-2}
Bucket dropped during emplacement	1.4×10^{-7}	5.8×10^{-8}	5.7×10^{-11}	2.3×10^{-11}	2.3×10^{-8}	1.0×10^{-9}	1.2×10^{-11}	5.2×10^{-13}	2.0×10^{-5}	1.9×10^{-7}	1.0×10^{-8}	9.3×10^{-11}	1.0×10^{-5}
Failure of release - opens early during bucket emplacement	7.1×10^{-7}	2.8×10^{-7}	2.8×10^{-10}	1.1×10^{-10}	1.2×10^{-7}	5.1×10^{-9}	5.8×10^{-11}	2.6×10^{-12}	1.0×10^{-4}	$9.1\times10x^{-7}$	5.0×10^{-8}	4.6×10^{-10}	1.0×10^{-5}
Mixing system breaks pellets during emplacement	1.4×10^{-8}	5.8×10^{-9}	5.7×10^{-12}	2.3×10^{-12}	2.3×10^{-9}	1.0×10^{-10}	1.2×10^{-12}	5.2×10^{-14}	2.0×10^{-6}	1.9×10^{-8}	1.0×10^{-9}	9.3×10^{-12}	1.0×10^{-3}
Pellets break during bucket emplacement release	1.4×10^{-8}	5.8×10^{-9}	5.7×10^{-12}	2.3×10^{-12}	2.3×10^{-9}	1.0×10^{-10}	1.2×10^{-12}	5.2×10^{-14}	2.0×10^{-6}	1.9×10^{-8}	1.0×10^{-9}	9.3×10^{-12}	1.0×10^{-3}

Table M.5.3.4.2–1. Immobilized Disposition at the Deep Borehole Complex Accident Impacts Ranges at Generic Site—Continued

	Worker at 1,000 m				Maximum Offsite Individual				Population to 80 km				
	Dose (rem)		Probability of Cancer Fatality[a]		Dose (rem)		Probability of Cancer Fatality[a]		Dose (person-rem)		Number of Cancer Fatalities[b]		Accident Frequency (per year)
Accident Scenario	High	Low	High	Low	High	Low	High	Low	High	High	Low	Low	
Rupture of delivering pipe during pumped emplacement	8.5×10^{-8}	3.4×10^{-8}	3.4×10^{-11}	1.4×10^{-11}	1.4×10^{-8}	6.2×10^{-10}	7.2×10^{-12}	3.1×10^{-13}	1.2×10^{-5}	1.1×10^{-7}	6.0×10^{-9}	5.5×10^{-11}	1.0×10^{-5}
Delivering pipe dropped during pumped emplacement	1.7×10^{-8}	6.9×10^{-9}	6.8×10^{-12}	2.7×10^{-12}	2.8×10^{-9}	1.2×10^{-10}	1.4×10^{-12}	6.2×10^{-14}	2.4×10^{-6}	2.2×10^{-8}	1.2×10^{-9}	1.1×10^{-11}	1.0×10^{-5}
Mixing system breaks pellets during pumped emplacement	1.7×10^{-9}	6.9×10^{-10}	6.8×10^{-13}	2.7×10^{-13}	2.8×10^{-10}	1.2×10^{-11}	1.4×10^{-13}	6.2×10^{-15}	2.4×10^{-7}	2.2×10^{-9}	1.2×10^{-10}	1.1×10^{-12}	1.0×10^{-3}
Pellets break during pumped emplacement release	1.7×10^{-9}	6.9×10^{-10}	6.8×10^{-13}	2.7×10^{-13}	2.8×10^{-10}	1.2×10^{-11}	1.4×10^{-13}	6.2×10^{-15}	2.4×10^{-7}	2.2×10^{-9}	1.2×10^{-10}	1.1×10^{-12}	1.0×10^{-3}
Failure of ventilation filter	8.5×10^{-10}	3.4×10^{-10}	3.4×10^{-13}	1.4×10^{-13}	1.4×10^{-10}	6.2×10^{-12}	6.9×10^{-14}	3.1×10^{-15}	1.2×10^{-7}	1.1×10^{-9}	6.0×10^{-11}	5.5×10^{-13}	1.0×10^{-6}
Uncontrolled chemical reaction	1.4×10^{-9}	5.8×10^{-10}	5.7×10^{-13}	2.3×10^{-13}	2.3×10^{-10}	1.0×10^{-11}	1.2×10^{-13}	5.2×10^{-15}	2.0×10^{-7}	1.9×10^{-9}	1.0×10^{-10}	9.3×10^{-13}	1.0×10^{-6}
Pellet storage nuclear criticality	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	6.6×10^{-3}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}
Pellet-grout mixing nuclear criticality	3.5×10^{-2}	1.6×10^{-2}	1.4×10^{-5}	6.2×10^{-6}	5.8×10^{-3}	2.0×10^{-4}	2.9×10^{-6}	1.0×10^{-7}	1.3	6.6×10^{-3}	6.3×10^{-4}	3.3×10^{-6}	1.0×10^{-6}

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Source: Calculated using the source terms in Tables M.5.3.3.1–3 and M.5.3.3.1–4 and the MACCS computer code.

M.5.3.5 Vitrification Alternative

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a vitrification facility in the *Fissile Material Disposition Program PEIS Data Call Input Report: New Glass Vitrification Facility*. The studies postulated a set of accident scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risk that are expected to envelope the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than 1.0×10^{-7}/yr are anticipated that will have consequences and risks larger than those described in this section. The potential for an aircraft crash has been considered and dismissed because the probability of a crash into a facility and causing sufficient damage to release Pu is much less than 10^{-7}/yr.

M.5.3.5.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, seven evaluation basis accidents and three beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.5.1–1 and M.5.3.5.1–2. Accident source term information is provided in Tables M.5.3.5.1–3 and M.5.3.5.1–4. Descriptions of accident scenarios are provided in Table M.5.3.5.1–5.

Table M.5.3.5.1–1. Evaluation Basis Accident Scenarios for the Vitrification Alternative

Accident Scenario	Accident Frequency (per year)	Source Term	
		At Risk	Released to Environment
Blender spill	0.01 to 0.1	82.5 kg Pu 9.23×10^{4} Ci Cs	1.24×10^{-5} g Pu 1.38×10^{-5} Ci Cs
Loss of offsite power	0.01 to 0.1	No release	No release
Melter spill	1.0×10^{-4} to 0.01	82.5 kg Pu 9.23×10^{4} Ci Cs	6.2×10^{-7} g Pu 6.9×10^{-7} Ci Cs
Cs capsule drop	1.0×10^{-4} to 0.01	70 kCi Cs	1.75×10^{-5} Ci Cs
Canister drop	1.0×10^{-4} to 0.01	82.5 kg Pu 9.23×10^{4} Ci Cs	6.1×10^{-6} g Pu 6.83×10^{-6} Ci Cs
CPC ion column fire	1.0×10^{-4} to 0.01	9.23×10^{4} Ci Cs	0.23 Ci Cs
Pu oxide solids fire oven	1.0×10^{-4} to 0.01	5 kg Pu	1.5×10^{-8} g Pu
Earthquake	1.0×10^{-6} to 1.0×10^{-4}	170 kg Pu 347 Ci Cs	3.86×10^{-4} g Pu 6.59×10^{-7} Ci Cs
Tornado	1.0×10^{-6} to 1.0×10^{-4}	No release	No release
Flood	1.0×10^{-6} to 1.0×10^{-4}	No release	No release

Source: LLNL 1996c.

Table M.5.3.5.1–2. Beyond Evaluation Basis Accident Scenarios for the Vitrification Alternative

Accident Scenario	Accident Frequency (per year)	Source Term	
		At Risk	Released to Environment
Cs fire	$<1.0 \times 10^{-6}$	1.3×10^{6} Ci Cs	1.3 Ci Cs
Blender fire	$<1.0 \times 10^{-6}$	82.5 kg Pu 9.23×10^{4} Ci Cs	5.16×10^{-5} g Pu 0.231 Ci Cs
Nuclear criticality in Pu oxide oven	$<1.0 \times 10^{-6}$	1.0×10^{18} fissions. Release fractions: 0.5 noble gases, 0.05 iodine.	[a]

[a] See Table M.5.3.5.1–4.

Source: LLNL 1996c.

Table M.5.3.5.1–3. Vitrification Alternative Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario						
	Blender Spill	Melter Spill	Cs Capsule Drop	Canister Drop	CPC Ion Column Fire	Pu Oxide Oven Solids Fire	Earthquake
Frequency of occurrence[a](per year)	0.05	$1.0x10^{-3}$/yr	$1.0x10^{-3}$/yr	$1.0x10^{-3}$/yr	$1.0x10^{-3}$/yr	$1.0x10^{-3}$/yr	$1.0x10^{-5}$/yr
Pu released to environment (g)	$1.24x10^{-5}$	$6.2x10^{-7}$	NA	$6.1x10^{-6}$	NA	$1.5x10^{-8}$	$3.86x10^{-4}$
Cs released to environment (Ci)	$1.38x10^{-5}$	$6.9x10^{-7}$	$1.75x10^{-5}$	$6.83x10^{-6}$	0.23	NA	$6.59x10^{-7}$
Isotope Released to Environment (Ci)							
Pu-238	$1.96x10^{-8}$	$9.80x10^{-10}$	0	$9.64x10^{-9}$	0	$2.37x10^{-11}$	$6.10x10^{-7}$
Pu-239	$7.09x10^{-7}$	$3.55x10^{-8}$	0	$3.49x10^{-7}$	0	$8.58x10^{-10}$	$2.21x10^{-5}$
Pu-240	$1.88x10^{-7}$	$9.42x10^{-9}$	0	$9.27x10^{-8}$	0	$2.28x10^{-10}$	$5.87x10^{-6}$
Pu-241	$6.68x10^{-7}$	$3.34x10^{-8}$	0	$3.29x10^{-7}$	0	$8.08x10^{-10}$	$2.08x10^{-5}$
Pu-242	$2.77x10^{-11}$	$1.38x10^{-12}$	0	$1.36x10^{-11}$	0	$3.34x10^{-14}$	$8.61x10^{-10}$
Am-241	$3.52x10^{-9}$	$1.76x10^{-10}$	0	$1.73x10^{-9}$	0	$4.26x10^{-12}$	$1.10x10^{-7}$
Cs-137	$1.38x10^{-5}$	$6.9x10^{-7}$	$1.75x10^{-5}$	$6.83x10^{-6}$	0.23	0	$6.59x10^{-7}$

[a] Midpoint of the estimated frequency range.

Note: Am=Americium; NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1 and M.5.3.5.1–1.

Table M.5.3.5.1–4. Vitrification Alternative Beyond Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario		
	Cs Fire	Blender Fire	Nuclear Criticality in Pu Oxide Furnace[a]
Frequency of occurrence (per year)	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Pu released to environment (g)	NA	5.16×10^{-5}	NA
Cs released to environment (Ci)	1.3	0.231	NA
Fissions	NA	NA	1.0×10^{18}
Isotope Released to Environment (Ci)			
Pu-238	0	8.15×10^{-8}	0
Pu-239	0	2.95×10^{-6}	0
Pu-240	0	7.84×10^{-7}	0
Pu-241	0	2.78×10^{-6}	0
Pu-242	0	1.15×10^{-10}	0
Am-241	0	1.47×10^{-8}	0
Cs-137	1.3	0.231	0
Kr-83m	0	0	5.5
Kr-85m	0	0	3.55
Kr-85	0	0	4.05×10^{-5}
Kr-87	0	0	21.5
Kr-88	0	0	11.5
Kr-89	0	0	650
Xe-131m	0	0	5.0×10^{-3}
Xe-133m	0	0	0.11
Xe-133	0	0	1.35
Xe-135m	0	0	165
Xe-135	0	0	20.5
Xe-137	0	0	2.45×10^{3}
Xe-138	0	0	550
I-131	0	0	0.055
I-132	0	0	6
I-133	0	0	0.8
I-134	0	0	21.5
I-135	0	0	2.25

[a] Curies produced (by isotope) or the 1.0×10^{18} fission criticality were scaled from Table M.5.3.1.1–3.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.5.1–2.

Table M.5.3.5.1–5. Accident Scenario Descriptions for the Vitrification Alternative

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Blender spill	The spill occurs as material is transferred from the blender to the melter. Fine particulate materials that became airborne during the spill would be removed from the area by the ventilation system and passed through HEPA filters before release to the environment.
Melter spill	The source document provided summary data in a tabular format for this accident scenario. This accident scenario was not described in the source document.
Cs capsule drop	The source document provided summary data in a tabular format for this accident scenario. This accident scenario was not described in the source document.
Canister drop	It was postulated that the impact shatters the glass and disperses the fragments into the cell atmosphere. Fine particulate materials that became airborne would be removed from the area by the ventilation system and passed through HEPA filters before release to the environment.
CPC ion column fire	The source document provided summary data in a tabular format for this accident scenario. This accident scenario was not described in the source document.
Pu oxide oven solids fire	The source document provided summary data in a tabular format for this accident scenario. This accident scenario was not described in the source document.
Earthquake	Contents of the blender, melter, Pu oxide oven the Cs preparation cell would be spilled. Fine particulate materials that became airborne during the spills would be removed from the area by the ventilation system and passed through HEPA filters before release to the environment.
Beyond Evaluation Basis Accidents	
Cs fire	The combustible load for the processes involving Cs is very low. The Cs is in the form of CsCl which is not flammable. A large fire was postulated in the process area and all Cs effected by the fire was released to the area ventilation system and passed through HEPA filters before release to the environment.
Blender fire	The combustible load in the process is very low. The process involves no flammable material. A large fire was postulated in the process cell. It is assumed that the fire ruptures the blender and the blender contents are exposed to the fire. The resultant airborne material is removed by the area ventilation system and passed through HEPA filters before release to the environment.
Nuclear criticality in Pu oxide furnace	A criticality event was assumed to occur in the Pu oxide oven process area and the assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.

Source: LLNL 1996c.

M.5.3.5.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.3.5.2–1 through M.5.3.5.2–6. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 using the MACCS computer code. [Text deleted.]

Table M.5.3.5.2–1. Vitrification Alternative Accident Impacts at Hanford Site

Accident Scenario	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		Accident Frequency (per year)
	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	
Blender spill	4.6×10^{-6}	1.8×10^{-9}	3.4×10^{-8}	1.7×10^{-11}	3.1×10^{-4}	1.5×10^{-7}	0.05
Melter spill	2.3×10^{-7}	9.1×10^{-11}	1.7×10^{-9}	8.6×10^{-13}	1.5×10^{-5}	7.6×10^{-9}	1.0×10^{-3}
Cs capsule drop	1.3×10^{-6}	5.3×10^{-10}	8.0×10^{-9}	4.0×10^{-12}	1.3×10^{-4}	6.4×10^{-8}	1.0×10^{-3}
Canister drop	2.2×10^{-6}	9.0×10^{-10}	1.7×10^{-8}	8.5×10^{-12}	1.5×10^{-4}	7.5×10^{-8}	1.0×10^{-3}
Cs ion processing fire	0.017	6.9×10^{-6}	1.1×10^{-4}	5.3×10^{-8}	1.7	8.4×10^{-4}	1.0×10^{-3}
Pu oxide oven solids fire	4.3×10^{-9}	1.7×10^{-12}	3.4×10^{-11}	1.7×10^{-14}	2.5×10^{-7}	1.2×10^{-10}	1.0×10^{-3}
Earthquake	1.1×10^{-4}	4.4×10^{-8}	8.8×10^{-7}	4.4×10^{-10}	6.4×10^{-3}	3.2×10^{-6}	1.0×10^{-5}
Cs fire	0.098	3.9×10^{-5}	6.0×10^{-4}	3.0×10^{-7}	9.5	4.7×10^{-3}	1.0×10^{-6}
Blender fire	0.017	7.0×10^{-6}	1.1×10^{-4}	5.3×10^{-8}	1.7	8.4×10^{-4}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	1.0×10^{-3}	4.2×10^{-7}	6.5×10^{-6}	3.3×10^{-9}	7.0×10^{-3}	3.5×10^{-6}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

Table M.5.3.5.2–2. Vitrification Alternative Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Blender spill	3.1×10^{-6}	1.2×10^{-9}	5.5×10^{-8}	2.8×10^{-11}	7.0×10^{-6}	3.5×10^{-9}	0.05
Melter spill	1.6×10^{-7}	6.2×10^{-11}	2.7×10^{-9}	1.4×10^{-12}	3.5×10^{-7}	1.7×10^{-10}	1.0×10^{-3}
Cs capsule drop	8.9×10^{-7}	3.6×10^{-10}	1.3×10^{-8}	6.6×10^{-12}	3.0×10^{-6}	1.5×10^{-9}	1.0×10^{-3}
Canister drop	1.5×10^{-6}	6.1×10^{-10}	2.7×10^{-8}	1.4×10^{-11}	3.4×10^{-6}	1.7×10^{-9}	1.0×10^{-3}
Cs ion processing fire	0.012	4.7×10^{-6}	1.7×10^{-4}	8.7×10^{-8}	0.039	1.9×10^{-5}	1.0×10^{-3}
Pu oxide oven solids fire	2.9×10^{-9}	1.2×10^{-12}	5.4×10^{-11}	2.7×10^{-14}	5.6×10^{-9}	2.8×10^{-12}	1.0×10^{-3}
Earthquake	7.5×10^{-5}	3.0×10^{-8}	1.4×10^{-6}	9.0×10^{-10}	1.4×10^{-4}	7.2×10^{-8}	1.0×10^{-5}
Cs fire	0.066	2.6×10^{-5}	9.8×10^{-4}	4.9×10^{-7}	0.22	1.1×10^{-4}	1.0×10^{-6}
Blender fire	0.012	4.7×10^{-6}	1.8×10^{-4}	8.7×10^{-8}	0.039	2.0×10^{-5}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	7.7×10^{-4}	3.1×10^{-7}	1.3×10^{-5}	6.5×10^{-9}	1.4×10^{-4}	6.9×10^{-8}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

Table M.5.3.5.2–3. Vitrification Alternative Accident Impacts at Idaho National Engineering Laboratory

Accident Scenario	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		Accident Frequency (per year)
	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	
Blender spill	4.2×10^{-6}	1.7×10^{-9}	3.5×10^{-8}	1.7×10^{-11}	9.3×10^{-5}	4.7×10^{-8}	0.05
Melter spill	2.1×10^{-7}	8.4×10^{-11}	1.7×10^{-9}	8.7×10^{-13}	4.7×10^{-6}	2.3×10^{-9}	1.0×10^{-3}
Cs capsule drop	1.2×10^{-6}	4.6×10^{-10}	7.7×10^{-9}	3.8×10^{-12}	4.0×10^{-5}	2.0×10^{-8}	1.0×10^{-3}
Canister drop	2.1×10^{-6}	8.3×10^{-10}	1.7×10^{-8}	8.5×10^{-12}	4.6×10^{-5}	2.3×10^{-8}	1.0×10^{-3}
Cs ion processing fire	0.015	6.1×10^{-6}	1.0×10^{-4}	5.0×10^{-8}	0.53	2.6×10^{-4}	1.0×10^{-3}
Pu oxide oven solids fire	4.0×10^{-9}	1.6×10^{-12}	3.4×10^{-11}	1.7×10^{-14}	7.4×10^{-8}	3.7×10^{-11}	1.0×10^{-3}
Earthquake	1.0×10^{-4}	4.1×10^{-8}	8.8×10^{-7}	4.4×10^{-10}	1.9×10^{-3}	9.6×10^{-7}	1.0×10^{-5}
Cs fire	0.086	3.4×10^{-5}	5.7×10^{-4}	2.9×10^{-7}	3.0	1.5×10^{-3}	1.0×10^{-6}
Blender fire	0.015	6.1×10^{-6}	1.0×10^{-4}	5.1×10^{-8}	0.53	2.7×10^{-4}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	1.0×10^{-3}	4.0×10^{-7}	7.7×10^{-6}	3.9×10^{-9}	1.8×10^{-3}	9.0×10^{-7}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

Table M.5.3.5.2–4. Vitrification Alternative Accident Impacts at Pantex Plant

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Blender spill	1.9×10^{-6}	7.5×10^{-10}	4.2×10^{-7}	2.1×10^{-10}	1.0×10^{-4}	5.0×10^{-8}	0.05
Melter spill	9.3×10^{-8}	3.7×10^{-11}	2.1×10^{-8}	1.0×10^{-11}	5.0×10^{-6}	2.5×10^{-9}	1.0×10^{-3}
Cs capsule drop	5.6×10^{-7}	2.2×10^{-10}	1.2×10^{-7}	5.9×10^{-11}	3.8×10^{-5}	1.9×10^{-8}	1.0×10^{-3}
Canister drop	9.2×10^{-7}	3.7×10^{-10}	2.1×10^{-7}	1.0×10^{-10}	4.9×10^{-5}	2.5×10^{-8}	1.0×10^{-3}
Cs ion processing fire	7.4×10^{-3}	3.0×10^{-6}	1.5×10^{-3}	7.7×10^{-7}	0.51	2.5×10^{-4}	1.0×10^{-3}
Pu oxide oven solids fire	1.7×10^{-9}	6.9×10^{-13}	4.0×10^{-10}	2.0×10^{-13}	8.4×10^{-8}	4.2×10^{-11}	1.0×10^{-3}
Earthquake	4.4×10^{-5}	1.8×10^{-8}	1.0×10^{-5}	5.1×10^{-9}	2.2×10^{-3}	1.1×10^{-6}	1.0×10^{-5}
Cs fire	0.042	1.7×10^{-5}	8.7×10^{-3}	4.4×10^{-6}	2.9	1.4×10^{-3}	1.0×10^{-6}
Blender fire	7.4×10^{-3}	3.0×10^{-6}	1.6×10^{-3}	7.8×10^{-7}	0.51	2.5×10^{-4}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	4.8×10^{-4}	1.9×10^{-7}	1.4×10^{-4}	7.0×10^{-8}	4.5×10^{-3}	2.2×10^{-6}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

Table M.5.3.5.2–5. Vitrification Alternative Accident Impacts at Oak Ridge Reservation

Accident Scenario	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		Accident Frequency (per year)
	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	
Blender spill	4.3×10^{-6}	1.7×10^{-9}	7.3×10^{-7}	3.7×10^{-10}	7.1×10^{-4}	3.5×10^{-7}	0.05
Melter spill	2.1×10^{-7}	8.6×10^{-11}	3.7×10^{-8}	1.8×10^{-11}	3.5×10^{-5}	1.8×10^{-8}	1.0×10^{-3}
Cs capsule drop	1.3×10^{-6}	5.2×10^{-10}	2.1×10^{-7}	1.0×10^{-10}	2.7×10^{-4}	1.3×10^{-7}	1.0×10^{-3}
Canister drop	2.1×10^{-6}	8.4×10^{-10}	3.6×10^{-7}	1.8×10^{-10}	3.5×10^{-4}	1.7×10^{-7}	1.0×10^{-3}
Cs ion processing fire	0.017	6.8×10^{-6}	2.7×10^{-3}	1.4×10^{-6}	3.5	1.8×10^{-3}	1.0×10^{-3}
Pu oxide oven solids fire	3.9×10^{-9}	1.6×10^{-12}	6.9×10^{-10}	3.5×10^{-13}	6.0×10^{-7}	3.0×10^{-10}	1.0×10^{-3}
Earthquake	1.0×10^{-4}	4.1×10^{-8}	1.8×10^{-5}	8.9×10^{-9}	0.015	7.7×10^{-6}	1.0×10^{-5}
Cs fire	0.095	3.8×10^{-5}	0.015	7.7×10^{-6}	19.8	9.9×10^{-3}	1.0×10^{-6}
Blender fire	0.017	6.8×10^{-6}	2.7×10^{-3}	1.4×10^{-6}	3.5	1.8×10^{-3}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	9.5×10^{-4}	3.8×10^{-7}	1.7×10^{-4}	8.5×10^{-8}	0.031	1.6×10^{-5}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary [1,000 m for this facility at ORR], whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

Table M.5.3.5.2–6. Vitrification Alternative Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Blender spill	3.0×10^{-6}	1.2×10^{-9}	5.8×10^{-8}	2.9×10^{-11}	3.2×10^{-4}	1.6×10^{-7}	0.05
Melter spill	1.5×10^{-7}	6.1×10^{-11}	2.9×10^{-9}	1.5×10^{-12}	1.6×10^{-5}	8.0×10^{-9}	1.0×10^{-3}
Cs capsule drop	9.2×10^{-7}	3.7×10^{-10}	1.6×10^{-8}	8.2×10^{-12}	1.3×10^{-4}	6.4×10^{-8}	1.0×10^{-3}
Canister drop	1.5×10^{-6}	6.0×10^{-10}	2.9×10^{-8}	1.4×10^{-11}	1.6×10^{-4}	7.9×10^{-8}	1.0×10^{-3}
Cs ion processing fire	0.012	4.8×10^{-6}	2.2×10^{-4}	1.1×10^{-7}	1.7	8.4×10^{-4}	1.0×10^{-3}
Pu oxide oven solids fire	2.8×10^{-9}	1.1×10^{-12}	5.5×10^{-11}	2.7×10^{-12}	2.7×10^{-7}	1.3×10^{-10}	1.0×10^{-3}
Earthquake	7.2×10^{-5}	2.9×10^{-8}	1.4×10^{-6}	7.1×10^{-10}	6.8×10^{-3}	3.4×10^{-8}	1.0×10^{-5}
Cs fire	0.068	2.7×10^{-5}	1.2×10^{-3}	6.1×10^{-7}	9.5	4.7×10^{-3}	1.0×10^{-6}
Blender fire	0.012	4.8×10^{-6}	2.2×10^{-4}	1.1×10^{-7}	1.7	8.4×10^{-4}	1.0×10^{-6}
Nuclear criticality in Pu oxide furnace	6.9×10^{-4}	2.8×10^{-7}	1.1×10^{-5}	5.7×10^{-9}	9.4×10^{-3}	4.7×10^{-6}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.5.1–3 and M.5.3.5.1–4 and the MACCS computer code.

M.5.3.6 Ceramic Immobilization Alternative

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a ceramic immobilized facility in the *Fissile Material Disposition Program PEIS Data Call Input Report: Ceramic Immobilization Facility with Radionuclides*. The studies postulated a set of accidents scenarios that were representative of the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risk that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than $1.0x10^{-7}$ per year are anticipated that will have consequences and risks larger than those described in this section. The potential for an aircraft crash has been considered and dismissed because the probability of a crash into a facility and causing sufficient damage to release Pu is much less than 10^{-7}/yr.

M.5.3.6.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public of operating the facility. Through a screening process, nine evaluation basis accidents and four beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.6.1–1 and M.5.3.6.1–2. Accident source term information is provided in Tables M.5.3.6.1–3 and M.5.3.6.1–4. Descriptions of accident scenarios are provided in Table M.5.3.6.1–5.

Table M.5.3.6.1–1. Evaluation Basis Accident Scenarios for the Ceramic Immobilization Alternative

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Earthquake	$1.0x10^{-6}$ to $1.0x10^{-4}$	7 kg Pu	$7.0x10^{-6}$ g Pu
Tornado	$1.0x10^{-6}$ to $1.0x10^{-4}$	No Release	No Release
Flood	$1.0x10^{-6}$ to $1.0x10^{-4}$	No Release	No Release
Glovebox fire	$1.0x10^{-6}$ to $1.0x10^{-4}$	7 kg Pu	$7.0x10^{-6}$ g Pu
Glovebox nuclear criticality	$1.0x10^{-6}$ to $1.0x10^{-4}$	10^{18} fissions. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]
Mixing tank nuclear criticality	$1.0x10^{-6}$ to $1.0x10^{-4}$	$1.0x10^{19}$ fissions total. $1.0x10^{18}$ fissions initial, 47 pulses of $1.0x10^{17}$ fissions at 10 minute intervals. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]
Bellows drop	$1.0x10^{-4}$ to 0.01	4 kg Pu 4,330 Ci Cs	$4.0x10^{-9}$g Pu $4.3x10^{-9}$ Ci Cs
Canister drop	$1.0x10^{-4}$ to 0.01	No Release	No Release
Cs capsule drop	$1.0x10^{-4}$ to 0.01	$4.0x10^{7}$ Ci Cs	$4.0x10^{-5}$ Ci Cs
Plutonyl nitrate dissolver spill	0.01 to 0.1	0.4 kg Pu	$2.4x10^{-11}$ g Pu
Calciner feed spill	0.01 to 0.1	2.5 kg Pu 2,740 Ci Cs	$1.25x10^{-10}$ g Pu $1.37x10^{-10}$ Ci Cs
Calciner product spill	0.01 to 0.1	5 kg Pu 5,480 Ci Cs	$3.5x10^{-8}$ g Pu $3.8x10^{-8}$ Ci Cs
Loss of off-site power	0.01 to 0.1	No Release	No Release

[a] See Table M.5.3.6.1–3.

Source: LLNL 1996d; NRC 1979a.

Table M.5.3.6.1–2. Beyond Evaluation Basis Accident Scenarios for the Ceramic Immobilization Alternative

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Cs fire	$<1.0 \times 10^{-6}$	1.3×10^{6} Ci Cs	1.3×10^{-5} Ci Cs
Process cell fire	$<1.0 \times 10^{-6}$	50 kg Pu	5.0×10^{-7} g Pu
Nuclear criticality	$<1.0 \times 10^{-6}$	3.0×10^{20} fissions total. 5.0×10^{19} fissions initial, 47 pulses of 5.0×10^{18} fissions at 10 minute intervals. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]
Uncontrolled chemical reaction	$<1.0 \times 10^{-6}$	25 kg Pu 27,400 Ci Cs	2.5×10^{-7} g Pu 2.74×10^{-7} Ci Cs

[a] See Table M.5.3.6.1–4.

Source: LLNL 1996d; NRC 1979a.

Table M.5.3.6.1–3. Ceramic Immobilization Alternative Evaluation Basis Accident Source Terms

	Accident Scenario								
Accident Parameter	**Earthquake**	**Glovebox Fire**	**Glovebox Nuclear Criticality[a]**	**Mixing Tank Nuclear Criticality[a]**	**Bellows Drop**	**Cs Capsule Drop**	**Plutonyl Nitrate Dissolver Spill**	**Calciner Feed Spill**	**Calciner Product Spill**
Frequency of occurrence[b] (per year)	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-3}	1.0×10^{-3}	0.05	0.05	0.05
Pu released to environment (g)	7.0×10^{-6}	7.0×10^{-6}	NA	NA	4.0×10^{-9}	NA	2.4×10^{-11}	1.25×10^{-10}	3.5×10^{-8}
Cs released to environment (Ci)	NA	NA	NA	NA	4.3×10^{-9}	4.0×10^{-5}	NA	1.37×10^{-10}	3.8×10^{-8}
Fissions	NA	NA	1.0×10^{18}	1.0×10^{19}	NA	NA	NA	NA	NA
Isotope Released to Environment (Ci)									
Pu-238	1.11×10^{-8}	1.11×10^{-8}	0	0	6.32×10^{-12}	0	3.79×10^{-14}	1.98×10^{-13}	5.53×10^{-11}
Pu-239	4.00×10^{-7}	4.06×10^{-7}	0	0	2.79×10^{-10}	0	1.37×10^{-12}	7.15×10^{-12}	2.00×10^{-9}
Pu-240	1.06×10^{-7}	1.06×10^{-7}	0	0	6.08×10^{-11}	0	3.65×10^{-13}	1.90×10^{-12}	5.32×10^{-10}
Pu-241	3.77×10^{-7}	3.77×10^{-7}	0	0	2.16×10^{-10}	0	1.29×10^{-12}	6.74×10^{-12}	1.89×10^{-9}
Pu-242	1.56×10^{-11}	1.56×10^{-11}	0	0	8.92×10^{-15}	0	5.35×10^{-17}	2.79×10^{-16}	7.81×10^{-14}
Am-241	1.99×10^{-9}	1.99×10^{-9}	0	0	1.14×10^{-12}	0	6.82×10^{-15}	3.55×10^{-14}	9.94×10^{-12}
Cs-137	0	0	0	0	4.3×10^{-9}	4.0×10^{-5}	0	1.37×10^{-10}	3.8×10^{-8}
Kr-83m	0	0	11	110	0	0	0	0	0
Kr-85m	0	0	7.1	71	0	0	0	0	0
Kr-85	0	0	8.1×10^{-5}	8.1×10^{-4}	0	0	0	0	0
Kr-87	0	0	43	430	0	0	0	0	0
Kr-88	0	0	23	230	0	0	0	0	0
Kr-89	0	0	1.3×10^{3}	1.3×10^{4}	0	0	0	0	0

Table M.5.3.6.1–3. Ceramic Immobilization Alternative Evaluation Basis Accident Source Terms—Continued

	Accident Scenario								
Accident Parameter	**Earthquake**	**Glovebox Fire**	**Glovebox Nuclear Criticality[a]**	**Mixing Tank Nuclear Criticality[a]**	**Bellows Drop**	**Cs Capsule Drop**	**Plutonyl Nitrate Dissolver Spill**	**Calciner Feed Spill**	**Calciner Product Spill**
Xe-131m	0	0	0.01	0.1	0	0	0	0	0
Xe-133m	0	0	0.22	2.2	0	0	0	0	0
Xe-133	0	0	2.7	27	0	0	0	0	0
Xe-135m	0	0	330	3.3×10^3	0	0	0	0	0
Xe-135	0	0	41	410	0	0	0	0	0
Xe-137	0	0	4.9×10^3	4.9×10^4	0	0	0	0	0
Xe-138	0	0	1.1×10^3	1.1×10^4	0	0	0	0	0
I-131	0	0	0.28	2.75	0	0	0	0	0
I-132	0	0	30	300	0	0	0	0	0
I-133	0	0	4	40	0	0	0	0	0
I-134	0	0	108	1.08×10^3	0	0	0	0	0
I-135	0	0	11.3	113	0	0	0	0	0

[a] Curies produced (by isotope) for the 1.0×10^{18} and 1.0×10^{19} fission criticalities were scaled from Table M.5.3.1.1–3.

[b] Midpoint of estimated frequency range.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.6.1–1.

Table M.5.3.6.1–4. Ceramic Immobilization Alternative Beyond Evaluation Basis Accident Source Terms

	Accident Scenario			
Accident Parameter	**Cs Fire**	**Process Cell Fire**	**Nuclear Criticality[a]**	**Uncontrolled Chemical Reaction**
Frequency of occurrence (per year)[b]	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Pu released to environment (g)	NA	5.0×10^{-7}	NA	2.5×10^{-7} g
Cs released to environment (Ci)	1.3×10^{-5}	NA	NA	2.74×10^{-7}
Fissions	NA	NA	3.0×10^{20}	NA
Isotope Released to Environment (Ci)				
Pu-238	0	7.9×10^{-10}	0	3.95×10^{-10}
Pu-239	0	2.86×10^{-8}	0	1.43×10^{-8}
Pu-240	0	7.60×10^{-9}	0	3.80×10^{-9}
Pu-241	0	2.69×10^{-8}	0	1.35×10^{-8}
Pu-242	0	1.12×10^{-12}	0	5.58×10^{-13}
Am-241	0	1.42×10^{-10}	0	7.10×10^{-11}
Cs-137	1.3×10^{-5}	0	0	2.74×10^{-7}
Kr-83m	0	0	3.3×10^{3}	0
Kr-85m	0	0	2.13×10^{3}	0
Kr-85	0	0	0.0243	0
Kr-87	0	0	1.29×10^{4}	0
Kr-88	0	0	6.90×10^{3}	0
Kr-89	0	0	3.90×10^{5}	0
Xe-131m	0	0	3.0	0
Xe-133m	0	0	66	0
Xe-133	0	0	810	0
Xe-135m	0	0	9.9×10^{4}	0
Xe-135	0	0	1.23×10^{4}	0
Xe-137	0	0	1.47×10^{6}	0
Xe-138	0	0	3.3×10^{5}	0
I-131	0	0	82.5	0
I-132	0	0	9.0×10^{3}	0
I-133	0	0	1.2×10^{3}	0
I-134	0	0	3.23×10^{4}	0
I-135	0	0	3.38×10^{3}	0

[a] Curies produced (by isotope) for the 3.0×10^{20} fission criticality was scaled from Table M.5.3.1.1–3.

[b] Midpoint of estimated frequency range.

Note: NA=not applicable.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.6.1–2.

Table M.5.3.6.1–5. Accident Scenario Descriptions for Ceramic Immobilization Alternative

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Earthquake	It is assumed that the earthquake starts a fire in the room housing the Pu metal glovebox line. The fire is unimpeded and breaches a glovebox containing Pu. The glovebox inert atmosphere is lost and the Pu ignites. The ventilation system removes the Pu-containing gases from the area. The gasses pass through HEPA filters and are then released to the environment.
Glovebox fire	It is assumed that an unimpeded fire begins in the room housing the Pu metal glovebox line and breaches a glovebox containing Pu. The glovebox inert atmosphere is lost and the Pu ignites. The ventilation system removes the Pu-containing gases from the area. The gases pass through HEPA filters and are then released to the environment.
Glovebox nuclear criticality	It is assumed that controls are violated so that additional fissile material is introduced into a double batched glovebox. This results in a criticality.
Mixing tank nuclear criticality	It is assumed that controls are violated so that limits on fissile materials and poison controls are violated. A pulsed criticality event results.
Bellows drop	A bellows is dropped 6 m during handling. The force of the drop factures the ceramic material and ruptures the bellows. Respirable fines of ceramic are released to the cell and collected by the ventilation system. The airborne fines pass through HEPA filters and are released to the environment.
Cs capsule drop	A capsule is dropped 6 m during handling. The force of the drop fractures the CsCl material and ruptures the capsule. Respirable fines of CsCl are released to the cell and collected by the ventilation system. The airborne fines pass through HEPA filters and are released to the environment.
Plutonyl nitrate dissolver spill	It is postulated that the dissolver overflows the spills onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in two hours but some of the spill material is aerosolized and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Calciner feed spill	It is postulated that the calciner feed make-up tank overflows and spills onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in two hours but some of the spill material is aerosolized and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Calciner product spill	It is postulated that the calciner product bin overflow and spills powder onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in two hours but some of the spill becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Beyond Evaluation Basis Accidents	
Cs fire	The combustible load for the processes involving Cs is very low. The Cs is in the form of CsCl which is not flammable. A large fire was postulated in the process area and all Cs effected by the fire was released to the area ventilation system and passes through HEPA filters before release to the environment.
Process cell fire	The combustible load in the remote process cells is very low. The process involves no flammable material. A large fire was postulated in the process cell. It is assumed that the fire ruptures the calciner product bins and the contents are exposed to the fire. The resultant airborne material is removed by the area ventilation system and passed through HEPA filters before release to the environment.

Table M.5.3.6.1–5. Accident Scenario Descriptions for Ceramic Immobilization Alternative—Continued

Accident Scenario	Accident Description
Nuclear criticality	A criticality event was assumed to occur in the facility and the assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.
Uncontrolled chemical reaction	Radiolytic hydrogen will be produced in the solutions in the facility. It was assumed that hydrogen accumulated within tanks because the tanks were isolated from the gas treatment system from a considerable period of time. It was postulated that hydrogen detonated in the calciner feed tank and some of the tank contents became airborne. The resultant airborne material is removed by the area ventilation system and passed through HEPA filters before release to the environment.

Source: LLNL 1996d.

M.5.3.6.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.3.6.2–1 through M.5.3.6.2–6. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 using the MACCS computer code. [Text deleted.]

Table M.5.3.6.2–1. Ceramic Immobilization Alternative Accident Impacts at Hanford Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	2.0×10^{-6}	7.9×10^{-10}	1.6×10^{-8}	7.9×10^{-12}	1.2×10^{-4}	5.8×10^{-8}	1.0×10^{-5}
Glovebox fire	2.0×10^{-6}	7.9×10^{-10}	1.6×10^{-8}	7.9×10^{-12}	1.2×10^{-4}	5.8×10^{-8}	1.0×10^{-5}
Glovebox criticality	3.5×10^{-3}	1.4×10^{-6}	2.3×10^{-5}	1.2×10^{-8}	0.032	1.6×10^{-5}	1.0×10^{-5}
Mixing tank criticality	0.035	1.4×10^{-5}	2.3×10^{-4}	1.2×10^{-7}	0.32	1.6×10^{-4}	1.0×10^{-5}
Bellows drop	1.5×10^{-9}	5.8×10^{-13}	1.1×10^{-11}	5.5×10^{-15}	9.7×10^{-8}	4.9×10^{-11}	1.0×10^{-3}
Cesium capsule drop	3.0×10^{-6}	1.2×10^{-9}	1.8×10^{-8}	9.2×10^{-12}	2.9×10^{-4}	1.5×10^{-7}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	6.8×10^{-12}	2.7×10^{-15}	5.4×10^{-14}	2.7×10^{-17}	4.0×10^{-10}	2.0×10^{-13}	0.05
Calciner feed spill	4.6×10^{-11}	1.8×10^{-14}	3.5×10^{-13}	1.7×10^{-16}	3.1×10^{-9}	1.5×10^{-12}	0.05
Calciner product spill	1.3×10^{-8}	5.1×10^{-12}	9.7×10^{-11}	4.8×10^{-14}	8.5×10^{-7}	4.3×10^{-10}	0.05
Cesium fire	9.8×10^{-7}	3.9×10^{-10}	6.0×10^{-9}	3.0×10^{-12}	9.5×10^{-5}	4.7×10^{-8}	1.0×10^{-6}
Process cell fire	1.4×10^{-7}	5.7×10^{-11}	1.1×10^{-9}	5.7×10^{-13}	8.2×10^{-6}	4.1×10^{-9}	1.0×10^{-6}
Criticality	1.0	4.2×10^{-4}	6.9×10^{-3}	3.5×10^{-6}	9.5	4.8×10^{-3}	1.0×10^{-6}
Uncontrolled chemical reaction	9.1×10^{-8}	3.7×10^{-11}	7.0×10^{-10}	3.5×10^{-13}	6.1×10^{-6}	3.1×10^{-9}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

Table M.5.3.6.2–2. Ceramic Immobilization Alternative Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	1.4×10^{-6}	5.4×10^{-10}	2.5×10^{-8}	1.3×10^{-11}	2.6×10^{-6}	1.3×10^{-9}	1.0×10^{-5}
Glovebox fire	1.4×10^{-6}	5.4×10^{-10}	2.5×10^{-8}	1.3×10^{-11}	2.6×10^{-6}	1.3×10^{-9}	1.0×10^{-5}
Glovebox criticality	2.5×10^{-3}	1.0×10^{-6}	4.5×10^{-5}	2.3×10^{-8}	6.5×10^{-4}	3.3×10^{-7}	1.0×10^{-5}
Mixing tank criticality	0.025	1.0×10^{-5}	4.5×10^{-4}	2.3×10^{-7}	6.5×10^{-3}	3.3×10^{-6}	1.0×10^{-5}
Bellows drop	9.9×10^{-10}	4.0×10^{-13}	1.8×10^{-11}	8.8×10^{-15}	2.2×10^{-9}	1.1×10^{-12}	1.0×10^{-3}
Cesium capsule drop	2.0×10^{-6}	8.1×10^{-10}	3.0×10^{-8}	1.5×10^{-11}	6.7×10^{-6}	3.4×10^{-9}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	4.7×10^{-12}	1.9×10^{-15}	8.6×10^{-14}	4.3×10^{-17}	8.9×10^{-12}	4.5×10^{-15}	0.05
Calciner feed spill	3.1×10^{-11}	1.2×10^{-14}	5.5×10^{-13}	2.8×10^{-16}	7.0×10^{-11}	3.5×10^{-14}	0.05
Calciner product spill	8.7×10^{-9}	3.5×10^{-12}	1.5×10^{-10}	7.7×10^{-14}	2.0×10^{-8}	9.7×10^{-12}	0.05
Cesium fire	6.6×10^{-7}	2.6×10^{-10}	9.8×10^{-9}	4.9×10^{-12}	2.2×10^{-6}	1.1×10^{-9}	1.0×10^{-6}
Process cell fire	9.7×10^{-8}	3.9×10^{-11}	1.8×10^{-9}	9.0×10^{-13}	1.9×10^{-7}	9.3×10^{-11}	1.0×10^{-6}
Criticality	0.76	3.0×10^{-4}	0.014	6.8×10^{-6}	0.20	9.7×10^{-5}	1.0×10^{-6}
Uncontrolled chemical reaction	6.2×10^{-8}	2.5×10^{-11}	1.1×10^{-9}	5.5×10^{-13}	1.4×10^{-7}	7.0×10^{-11}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

Table M.5.3.6.2–3. Ceramic Immobilization Alternative Accident Impacts at Idaho National Engineering Laboratory

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	1.9×10^{-6}	7.4×10^{-10}	1.6×10^{-8}	8.0×10^{-12}	3.5×10^{-5}	1.7×10^{-8}	1.0×10^{-5}
Glovebox fire	1.9×10^{-6}	7.4×10^{-10}	1.6×10^{-8}	8.0×10^{-12}	3.5×10^{-5}	1.7×10^{-8}	1.0×10^{-5}
Glovebox nuclear criticality	3.4×10^{-3}	1.4×10^{-6}	2.7×10^{-5}	1.3×10^{-8}	8.7×10^{-3}	4.3×10^{-6}	1.0×10^{-5}
Mixing tank nuclear criticality	0.034	1.4×10^{-5}	2.7×10^{-4}	1.3×10^{-7}	0.086	4.3×10^{-5}	1.0×10^{-5}
Bellows drop	1.3×10^{-9}	5.4×10^{-13}	1.1×10^{-11}	5.5×10^{-15}	3.0×10^{-8}	1.5×10^{-11}	1.0×10^{-3}
Cesium capsule drop	2.6×10^{-6}	1.1×10^{-9}	1.8×10^{-8}	8.8×10^{-12}	9.2×10^{-5}	4.6×10^{-8}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	6.4×10^{-12}	2.5×10^{-15}	5.5×10^{-14}	2.8×10^{-17}	1.2×10^{-10}	5.9×10^{-14}	0.05
Calciner feed spill	4.2×10^{-11}	1.7×10^{-14}	3.5×10^{-13}	1.7×10^{-16}	9.3×10^{-10}	4.7×10^{-13}	0.05
Calciner product spill	1.2×10^{-8}	4.7×10^{-12}	9.7×10^{-11}	4.8×10^{-14}	2.6×10^{-7}	1.3×10^{-10}	0.05
Cesium fire	8.6×10^{-7}	3.4×10^{-10}	5.7×10^{-9}	2.9×10^{-12}	3.0×10^{-5}	1.5×10^{-8}	1.0×10^{-6}
Process cell fire	1.3×10^{-7}	5.3×10^{-11}	1.1×10^{-9}	5.7×10^{-13}	2.5×10^{-6}	1.2×10^{-9}	1.0×10^{-6}
Nuclear criticality	1.0	4.0×10^{-4}	8.1×10^{-3}	4.0×10^{-6}	2.6	1.3×10^{-3}	1.0×10^{-6}
Uncontrolled chemical reaction	8.4×10^{-8}	3.4×10^{-11}	6.9×10^{-10}	3.5×10^{-13}	1.9×10^{-6}	9.3×10^{-10}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

All values are mean values.

Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

Table M.5.3.6.2–4. Ceramic Immobilization Alternative Accident Impacts at Pantex Plant

Accident Scenario	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	8.0×10^{-7}	3.2×10^{-10}	1.8×10^{-7}	9.2×10^{-11}	3.9×10^{-5}	2.0×10^{-8}	1.0×10^{-5}
Glovebox fire	8.0×10^{-7}	3.2×10^{-10}	1.8×10^{-7}	9.2×10^{-11}	3.9×10^{-5}	2.0×10^{-8}	1.0×10^{-5}
Glovebox nuclear criticality	1.5×10^{-3}	6.2×10^{-7}	4.4×10^{-4}	2.2×10^{-7}	0.019	9.5×10^{-6}	1.0×10^{-5}
Mixing tank nuclear criticality	0.015	6.2×10^{-6}	4.4×10^{-3}	2.2×10^{-6}	0.19	9.5×10^{-5}	1.0×10^{-5}
Bellows drop	6.0×10^{-10}	2.4×10^{-13}	1.3×10^{-10}	6.7×10^{-14}	3.2×10^{-8}	1.6×10^{-11}	1.0×10^{-3}
Cesium capsule drop	1.3×10^{-6}	5.1×10^{-10}	2.7×10^{-7}	1.3×10^{-10}	8.8×10^{-5}	4.4×10^{-8}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	2.7×10^{-12}	1.1×10^{-15}	6.3×10^{-13}	3.2×10^{-16}	1.4×10^{-10}	6.7×10^{-14}	0.05
Calciner feed spill	1.9×10^{-11}	7.5×10^{-15}	4.2×10^{-12}	2.1×10^{-15}	1.0×10^{-9}	5.0×10^{-13}	0.05
Calciner product spill	5.2×10^{-9}	2.1×10^{-12}	1.2×10^{-9}	5.9×10^{-13}	2.8×10^{-7}	1.4×10^{-10}	0.05
Cesium fire	4.2×10^{-7}	1.7×10^{-10}	8.7×10^{-8}	4.4×10^{-11}	2.9×10^{-5}	1.4×10^{-8}	1.0×10^{-6}
Process cell fire	5.7×10^{-8}	2.3×10^{-11}	1.3×10^{-8}	6.6×10^{-12}	2.8×10^{-6}	1.4×10^{-9}	1.0×10^{-6}
Nuclear criticality	0.46	1.9×10^{-4}	0.13	6.5×10^{-5}	5.7	2.8×10^{-3}	1.0×10^{-6}
Uncontrolled chemical reaction	3.7×10^{-8}	1.5×10^{-11}	8.5×10^{-9}	4.2×10^{-12}	2.0×10^{-6}	1.0×10^{-9}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

All values are mean values.

Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

Table M.5.3.6.2–5. Ceramic Immobilization Alternative Accident Impacts at Oak Ridge Reservation

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	1.8×10^{-6}	7.3×10^{-10}	3.2×10^{-7}	1.6×10^{-10}	2.8×10^{-4}	1.4×10^{-7}	1.0×10^{-5}
Glovebox fire	1.8×10^{-6}	7.3×10^{-10}	3.2×10^{-7}	1.6×10^{-10}	2.8×10^{-4}	1.4×10^{-7}	1.0×10^{-5}
Glovebox nuclear criticality	3.2×10^{-3}	1.3×10^{-6}	5.8×10^{-4}	2.9×10^{-7}	0.13	6.3×10^{-5}	1.0×10^{-5}
Mixing tank nuclear criticality	0.032	1.3×10^{-5}	5.8×10^{-3}	2.9×10^{-6}	1.3	6.3×10^{-4}	1.0×10^{-5}
Bellows drop	1.4×10^{-9}	5.5×10^{-13}	2.4×10^{-10}	1.2×10^{-13}	2.3×10^{-7}	1.1×10^{-10}	1.0×10^{-3}
Cesium capsule drop	2.9×10^{-6}	1.2×10^{-9}	4.7×10^{-7}	2.4×10^{-10}	6.1×10^{-4}	3.1×10^{7}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	6.3×10^{-12}	2.5×10^{-15}	1.1×10^{-12}	5.5×10^{-16}	9.6×10^{-10}	4.8×10^{-13}	0.05
Calciner feed spill	4.3×10^{-11}	1.7×10^{-14}	7.4×10^{-12}	3.7×10^{-15}	7.1×10^{-9}	3.5×10^{-12}	0.05
Calciner product spill	1.2×10^{-8}	4.8×10^{-12}	2.1×10^{-9}	1.0×10^{-12}	2.0×10^{-6}	9.9×10^{-10}	0.05
Cesium fire	9.5×10^{-7}	3.8×10^{-10}	1.5×10^{-7}	7.7×10^{-11}	2.0×10^{-4}	9.9×10^{-8}	1.0×10^{-6}
Process cell fire	1.3×10^{-7}	5.3×10^{-11}	2.3×10^{-8}	1.2×10^{-11}	2.0×10^{-5}	1.0×10^{-8}	1.0×10^{-6}
Nuclear criticality	0.94	3.8×10^{-4}	0.17	8.6×10^{-5}	37.4	0.019	1.0×10^{-6}
Uncontrolled chemical reaction	8.6×10^{-8}	3.4×10^{-11}	1.5×10^{-8}	7.3×10^{-12}	0.14×10^{-5}	7.1×10^{-9}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary [1,000 m for this facility at ORR], whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

Table M.5.3.6.2–6. Ceramic Immobilization Alternative Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	1.3×10^{-6}	5.2×10^{-10}	2.6×10^{-8}	1.3×10^{-11}	1.2×10^{-4}	6.2×10^{-8}	1.0×10^{-5}
Glovebox fire	1.3×10^{-6}	5.2×10^{-10}	2.6×10^{-8}	1.3×10^{-11}	1.2×10^{-4}	6.2×10^{-8}	1.0×10^{-5}
Glovebox nuclear criticality	2.3×10^{-3}	9.1×10^{-7}	4.0×10^{-5}	2.0×10^{-8}	0.041	2.0×10^{-5}	1.0×10^{-5}
Mixing tank nuclear criticality	0.023	9.1×10^{-6}	4.0×10^{-4}	2.0×10^{-7}	0.41	2.0×10^{-4}	1.0×10^{-5}
Bellows drop	9.7×10^{-10}	3.9×10^{-13}	1.9×10^{-11}	9.3×10^{-15}	1.0×10^{-7}	5.1×10^{-11}	1.0×10^{-3}
Cesium capsule drop	2.1×10^{-6}	8.4×10^{-10}	3.8×10^{-8}	1.9×10^{-11}	2.9×10^{-4}	1.5×10^{-7}	1.0×10^{-3}
Plutonyl nitrate dissolver spill	4.5×10^{-12}	1.8×10^{-15}	8.8×10^{-14}	4.4×10^{-17}	4.2×10^{-10}	2.1×10^{-13}	0.05
Calciner feed spill	3.0×10^{-11}	1.2×10^{-14}	5.9×10^{-13}	2.9×10^{-16}	3.2×10^{-9}	1.6×10^{-12}	0.05
Calciner product spill	8.5×10^{-9}	3.4×10^{-12}	1.6×10^{-10}	8.2×10^{-12}	9.0×10^{-7}	4.5×10^{-10}	0.05
Cesium fire	6.8×10^{-7}	2.7×10^{-10}	1.2×10^{-8}	6.1×10^{-12}	9.5×10^{-5}	4.7×10^{-8}	1.0×10^{-6}
Process cell fire	9.3×10^{-8}	3.7×10^{-11}	1.8×10^{-9}	9.1×10^{-13}	8.8×10^{-6}	4.4×10^{-9}	1.0×10^{-6}
Nuclear criticality	0.68	2.7×10^{-4}	0.012	6.0×10^{-6}	12.2	6.1×10^{-3}	1.0×10^{-6}
Uncontrolled chemical reaction	6.1×10^{-8}	2.4×10^{-11}	1.2×10^{-9}	5.9×10^{-13}	6.4×10^{-6}	3.2×10^{-9}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.6.1–3 and M.5.3.6.1–4 and the MACCS computer code.

M.5.3.7 Ceramic Immobilization Facility for Immobilized Disposition Alternative

Studies of evaluation basis accidents and beyond evaluation basis accidents have been performed for a ceramic immobilization facility in the *Fissile Material Disposition Program PEIS Data Call Input Report: Ceramic Immobilization Facility Using Coated Pellets Without Radionuclides*. The studies postulated a set of accident scenarios that represented the risks and consequences for workers and the public that can be expected if the facility were constructed and operated. Although not all potential accidents were addressed, those that were postulated have consequences and risks that are expected to envelop the consequences and risks of an operating facility. In this manner, no other credible accidents with an expected frequency of occurrence larger than 1.0×10^{-7} per year are anticipated that will have consequences and risks larger than those described in this section. The potential for an aircraft crash has been considered and dismissed because the probability of a crash into a facility and causing sufficient damage to release Pu is much less than 10^{-7}/yr.

M.5.3.7.1 *Accident Scenarios and Source Terms*

A wide range of hazardous conditions and potential accidents were identified as candidates to represent the risks to workers and the public operating the facility. Through a screening process, nine evaluation basis accidents and three beyond evaluation basis accidents were selected for further definition and analysis. Descriptive information on these accidents is provided in Tables M.5.3.7.1–1 and M.5.3.7.1–2. Accident source term information is provided in Tables M.5.3.7.1–3 and M.5.3.7.1–4. Descriptions of accident scenarios are provided in Table M.5.3.7.1–5.

Table M.5.3.7.1–1. Evaluation Basis Accident Scenarios for Immobilized Disposition at the Ceramic Immobilization Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Earthquake	1.0×10^{-6} to 1.0×10^{-4}	20 kg Pu	2.0×10^{-5} g Pu
Tornado	1.0×10^{-6} to 1.0×10^{-4}	No Release	No Release
Flood	1.0×10^{-6} to 1.0×10^{-4}	No Release	No Release
Glovebox fire	1.0×10^{-6} to 1.0×10^{-4}	20 kg Pu	2.0×10^{-5} g Pu
Glovebox nuclear criticality	1.0×10^{-6} to 1.0×10^{-4}	1.0×10^{18} fissions. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]
Calciner feed tank nuclear criticality	1.0×10^{-6} to 1.0×10^{-4}	1.0×10^{19} fissions total, 1.0×10^{18} fissions initial, 47 pulses of 1.0×10^{17} fissions at 10 minute intervals. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]
Ceramic can drop	1.0×10^{-4} to 0.01	0.5 kg Pu	5.0×10^{-10} g Pu
Pellet container breakage	1.0×10^{-4} to 0.01	5 kg Pu	5.0×10^{-12} g Pu
Dissolver spill	0.01 to 0.1	0.4 kg Pu	2.4×10^{-11} g Pu
Calciner feed spill	0.01 to 0.1	1.4 kg Pu	7.0×10^{-11} g Pu
Calciner product spill	0.01 to 0.1	2.5 kg Pu	1.75×10^{-8} g Pu
Loss of offsite power	0.01 to 0.1	No Release	No Release

[a] See Table M.5.3.7.1–3.

Source: LLNL 1996e.

Table M.5.3.7.1–2. Beyond Evaluation Basis Accident Scenarios for Immobilized Disposition at the Ceramic Immobilization Facility

Accident Scenario	Accident Frequency (per year)	Source Term at Risk	Source Term Released to Environment
Sintering furnace explosion	$<1.0 \times 10^{-6}$	3 kg Pu	3.0×10^{-4} g Pu
Uncontrolled chemical reaction	$<1.0 \times 10^{-6}$	14 kg Pu	1.4×10^{-5} g Pu
Pu storage nuclear criticality	$<1.0 \times 10^{-6}$	10^{18} fissions. Release fractions: 1.0 noble gases, 0.25 halogens.	[a]

[a] See Table M.5.3.7.1–4.

Source: LLNL 1996e.

Table M.5.3.7.1–3. Immobilized Disposition at the Ceramic Immobilization Facility Evaluation Basis Accident Source Terms

	Accident Scenario								
Accident Parameter	**Earthquake**	**Glovebox Fire**	**Glovebox Nuclear Criticality[a]**	**Calciner Feed Nuclear Criticality[a]**	**Ceramic Can Drop**	**Pellet Container Breakage**	**Plutonyl Nitrate Dissolver Spill**	**Calciner Feed Spill**	**Calciner Product Spill**
Frequency of occurrence (per year)[b]	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-3}	1.0×10^{-3}	0.05	0.05	0.05
Pu released to environment (g)	2.0×10^{-5}	2.0×10^{-5}	NA	NA	5.0×10^{-10}	5.0×10^{-12}	2.4×10^{-11}	7.0×10^{-11}	1.75×10^{-8}
Fissions	NA	NA	1.0×10^{18}	1.0×10^{19}	NA	NA	NA	NA	NA
Isotope released to environment (Ci)									
Pu-238	3.16×10^{-8}	3.16×10^{-8}	0	0	7.90×10^{-13}	7.90×10^{-15}	3.79×10^{-14}	1.11×10^{-13}	2.77×10^{-11}
Pu-239	1.14×10^{-6}	1.14×10^{-6}	0	0	2.86×10^{-11}	2.86×10^{-13}	1.37×10^{-12}	4.00×10^{-12}	1.00×10^{-9}
Pu-240	3.04×10^{-7}	3.04×10^{-7}	0	0	7.60×10^{-12}	7.60×10^{-14}	3.65×10^{-13}	1.06×10^{-12}	2.66×10^{-10}
Pu-241	1.08×10^{-6}	1.08×10^{-6}	0	0	2.69×10^{-11}	2.69×10^{-13}	1.20×10^{-12}	3.77×10^{-12}	9.43×10^{-10}
Pu-242	4.46×10^{-11}	4.46×10^{-11}	0	0	1.11×10^{-15}	1.16×10^{-17}	5.35×10^{-17}	1.56×10^{-16}	3.90×10^{-14}
Am-241	5.68×10^{-9}	5.68×10^{-9}	0	0	1.42×10^{-13}	1.42×10^{-15}	6.82×10^{-15}	1.99×10^{-14}	4.97×10^{-12}
Cs-137	0	0	0	0	0	0	0	0	0
Kr-83m	0	0	11	110	0	0	0	0	0
Kr-85m	0	0	7.1	71	0	0	0	0	0
Kr-85	0	0	8.1×10^{-5}	8.1×10^{-4}	0	0	0	0	0
Kr-87	0	0	43	430	0	0	0	0	0
Kr-88	0	0	23	230	0	0	0	0	0
Kr-89	0	0	1.3×10^{3}	1.3×10^{4}	0	0	0	0	0
Xe-131m	0	0	0.01	0.1	0	0	0	0	0
Xe-133m	0	0	0.22	2.2	0	0	0	0	0
Xe-133	0	0	2.7	27	0	0	0	0	0
Xe-135m	0	0	330	3.3×10^{3}	0	0	0	0	0
Xe-135	0	0	41	410	0	0	0	0	0

Table M.5.3.7.1–3. Immobilized Disposition at the Ceramic Immobilization Facility Evaluation Basis Accident Source Terms—Continued

Accident Parameter	Accident Scenario								
	Earthquake	Glovebox Fire	Glovebox Nuclear Criticality[a]	Calciner Feed Nuclear Criticality[a]	Ceramic Can Drop	Pellet Container Breakage	Plutonyl Nitrate Dissolver Spill	Calciner Feed Spill	Calciner Product Spill
Xe-137	0	0	4.9×10^{3}	4.9×10^{4}	0	0	0	0	0
Xe-138	0	0	1.1×10^{3}	1.1×10^{4}	0	0	0	0	0
I-131	0	0	0.28	2.75	0	0	0	0	0
I-132	0	0	30	300	0	0	0	0	0
I-133	0	0	4	40	0	0	0	0	0
I-134	0	0	108	1.08×10^{3}	0	0	0	0	0
I-135	0	0	11.3	113	0	0	0	0	0

[a] Curies produced (by isotope) for the 1.0×10^{18} and 1.0×10^{19} fission criticalities were scaled from Table M.5.3.1.1–3.

[b] Midpoint of the estimated frequency range.

Note: All values are mean values.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.7.1–1.

Table M.5.3.7.1–4. Immobilized Disposition at the Ceramic Immobilization Facility Beyond Evaluation Basis Accident Source Terms

Accident Parameter	Accident Scenario		
	Sintering Furnace Explosion	Uncontrolled Chemical Reaction	Nuclear Criticality[a]
Frequency of occurrence (per year)[b]	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Pu released to environment (g)	3.0×10^{-4}	1.4×10^{-5}	NA
Fissions	NA	NA	1.0×10^{18}
Isotope Released to Environment (Ci)			
Pu-238	4.74×10^{-7}	2.21×10^{-8}	0
Pu-239	1.72×10^{-5}	8.01×10^{-7}	0
Pu-240	4.56×10^{-6}	2.13×10^{-7}	0
Pu-241	1.62×10^{-5}	7.55×10^{-7}	0
Pu-242	6.69×10^{-10}	3.12×10^{-11}	0
Am-241	8.52×10^{-8}	3.98×10^{-9}	0
Kr-83m	0	0	11
Kr-85m	0	0	7.1
Kr-85	0	0	8.1×10^{-5}
Kr-87	0	0	43
Kr-88	0	0	23
Kr-89	0	0	1.3×10^{3}
Xe-131m	0	0	0.01
Xe-133m	0	0	0.22
Xe-133	0	0	2.7
Xe-135m	0	0	330
Xe-135	0	0	41
Xe-137	0	0	4.9×10^{3}
Xe-138	0	0	1.1×10^{3}
I-131	0	0	0.28
I-132	0	0	30
I-133	0	0	4
I-134	0	0	108
I-135	0	0	11.3

[a] Curies produced (by isotope) for the 1.0×10^{18} fission criticality were scaled from Table M.5.3.1.1–3.

[b] Maximum of the estimated frequency range.

Note: All values are mean values.

Source: Derived from Tables M.5.1.3.4–1, M.5.3.1.1–3, and M.5.3.7.1–1.

Table M.5.3.7.1–5. Accident Scenario Descriptions for Immobilized Disposition at the Ceramic Immobilization Facility

Accident Scenario	Accident Description
Evaluation Basis Accidents	
Earthquake	It is assumed that the earthquake starts a fire in the room housing the plutonium metal glovebox line. The fire is unimpeded and breaches a glovebox containing plutonium. The glovebox inert atmosphere is lost and the Pu ignites. The ventilation system removes the Pu-containing gasses from the area. The gasses pass through HEPA filters and are then released to the environment.
Glovebox fire	It is assumed that an unimpeded fire begins in the room housing the Pu metal glovebox line and breaches a glovebox containing plutonium. The glovebox inert atmosphere is lost and the Pu ignites. The ventilation system removes the Pu-containing gases from the area. The gasses pass through HEPA filters and are then released to the environment.
Glovebox nuclear criticality	It is assumed that controls are violated so that additional fissile material is introduced into a double batched glovebox. This results in a criticality.
Calciner feed tank nuclear criticality	Criticality safety of this tank depends on controlling the concentrations of the gadolinium and plutonyl nitrate solutions in the tank. It is assumed that controls are violated so that limits on fissile materials and poison controls are violated. A pulsed criticality event results.
Ceramic can drop	A can is dropped during handling. The ceramic powder spills from the overturned can. Respirable fines of ceramic are released to the process area and collected by the ventilation system. The airborne fines pass through HEPA filters and are released to the environment.
Pellet container breakage	Finished ceramic pellets are loaded in drum containers and stored in the product storage vault. It is postulated that a container breakage could occur in ceramic pellet storage. A ceramic pellet container develops leakage during storage. Respirable fines of ceramic are released to the process area and collected by the ventilation system. The airborne fines pass through HEPA filters and are released to the environment.
Dissolver spill	It is postulated that the dissolver overflows and spills onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in 2 hours, but some of the spill material converts to an aerosol and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Calciner feed spill	It is postulated that the calciner feed make-up tank overflows and spills onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in 2 hours, but some of the spill material converts to an aerosol and becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Calciner product spill	It is postulated that the calciner product bin overflows and spills powder onto the floor. The spill spreads out in a safe geometry. The spill is cleaned up in 2 hours, but some of the spill becomes airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.

Table M.5.3.7.1–5. Accident Scenario Descriptions for Immobilized Disposition at the Ceramic Immobilization Facility—Continued

Accident Scenario	Accident Description
Beyond Evaluation Basis Accidents	
Sintering furnace explosion	A pressure excursion in the sintering furnace of undefined origin could rupture the furnace vessel. It was postulated that the force from the explosion would blow ceramic pellets out of the ends and become airborne as respirable particles. The Pu-containing particulate would be removed from the process area by the ventilation system. The particulate then passes through a HEPA filtration system before it is released to the environment.
Uncontrolled chemical reaction	Radiolytic hydrogen will be produced in the solutions in the facility. It was assumed that hydrogen accumulated within tanks because the tanks were isolated from the gas treatment system for a considerable period of time. It was postulated that hydrogen detonated in the calciner feed tank and some of it became airborne. The resultant airborne material is removed by the area ventilation system and passed through HEPA filters before release to the environment.
Nuclear criticality	A criticality event was assumed to occur in the facility and the assumed criticality accident severity is based on guidance provided in NRC Regulatory Guide 3.35.

Source: LLNL 1996e.

M.5.3.7.2 *Accident Impacts*

The estimated impacts of the postulated accidents at each site are provided in Tables M.5.3.7.2–1 through M.5.3.7.2–6. The dose and cancer fatality estimates are based on the analysis of the accident source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4, using the MACCS computer code. [Text deleted.]

Table M.5.3.7.2–1. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Hanford Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	5.7×10^{-6}	2.3×10^{-9}	4.5×10^{-8}	2.3×10^{-11}	3.3×10^{-4}	1.6×10^{-7}	1.0×10^{-5}
Glovebox fire	5.7×10^{-6}	2.3×10^{-9}	4.5×10^{-8}	2.3×10^{-11}	3.3×10^{-4}	1.6×10^{-7}	1.0×10^{-5}
Glovebox nuclear criticality	3.5×10^{-3}	1.4×10^{-6}	2.3×10^{-5}	1.2×10^{-8}	0.032	1.6×10^{-5}	1.0×10^{-5}
Calciner feed nuclear criticality	0.035	1.4×10^{-5}	2.3×10^{-4}	1.2×10^{-7}	0.32	1.6×10^{-4}	1.0×10^{-5}
Ceramic can drop	1.4×10^{-10}	5.7×10^{-14}	1.1×10^{-12}	5.7×10^{-16}	8.2×10^{-9}	4.1×10^{-12}	1.0×10^{-3}
Pellet container drop	1.4×10^{-12}	5.7×10^{-16}	1.1×10^{-14}	5.7×10^{-18}	8.2×10^{-11}	4.1×10^{-14}	1.0×10^{-3}
Dissolver spill	6.8×10^{-12}	2.7×10^{-15}	5.4×10^{-14}	2.7×10^{-17}	4.0×10^{-10}	2.0×10^{-13}	0.05
Calciner feed spill	2.0×10^{-11}	7.9×10^{-15}	1.6×10^{-13}	7.9×10^{-17}	1.2×10^{-9}	5.8×10^{-13}	0.05
Calciner product spill	5.0×10^{-9}	2.0×10^{-12}	4.0×10^{-11}	2.0×10^{-14}	2.9×10^{-7}	1.4×10^{-10}	0.05
Sintering furnace explosion	8.5×10^{-5}	3.4×10^{-8}	6.8×10^{-7}	3.4×10^{-10}	5.0×10^{-3}	2.5×10^{-6}	1.0×10^{-6}
Uncontrolled chemical reaction	4.0×10^{-6}	1.6×10^{-9}	3.2×10^{-8}	1.6×10^{-11}	2.3×10^{-4}	1.2×10^{-7}	1.0×10^{-6}
Nuclear criticality	3.5×10^{-3}	1.4×10^{-6}	2.3×10^{-5}	1.2×10^{-8}	0.032	1.6×10^{-5}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.

Table M.5.3.7.2–2. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Nevada Test Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	3.9×10^{-6}	1.6×10^{-9}	7.2×10^{-8}	3.6×10^{-11}	7.4×10^{-6}	3.7×10^{-9}	1.0×10^{-5}
Glovebox fire	3.9×10^{-6}	1.6×10^{-9}	7.2×10^{-8}	3.6×10^{-11}	7.4×10^{-6}	3.7×10^{-9}	1.0×10^{-5}
Glovebox nuclear criticality	2.5×10^{-3}	1.0×10^{-6}	4.5×10^{-5}	2.3×10^{-8}	6.5×10^{-4}	3.3×10^{-7}	1.0×10^{-5}
Calciner feed nuclear criticality	0.025	1.0×10^{-5}	4.5×10^{-4}	2.3×10^{-7}	6.5×10^{-3}	3.3×10^{-6}	1.0×10^{-5}
Ceramic can drop	9.7×10^{-11}	3.9×10^{-14}	1.8×10^{-12}	9.0×10^{-16}	1.9×10^{-10}	9.3×10^{-14}	1.0×10^{-3}
Pellet container drop	9.7×10^{-13}	3.9×10^{-16}	1.8×10^{-14}	9.0×10^{-18}	1.9×10^{-12}	9.3×10^{-16}	1.0×10^{-3}
Dissolver spill	4.7×10^{-12}	1.9×10^{-15}	8.6×10^{-14}	4.3×10^{-17}	8.9×10^{-12}	4.5×10^{-15}	0.05
Calciner feed spill	1.4×10^{-11}	5.4×10^{-15}	2.5×10^{-13}	1.3×10^{-16}	2.6×10^{-11}	1.3×10^{-14}	0.05
Calciner product spill	3.4×10^{-9}	1.4×10^{-12}	6.3×10^{-11}	3.1×10^{-14}	6.5×10^{-9}	3.3×10^{-12}	0.05
Sintering furnace explosion	5.8×10^{-5}	2.3×10^{-8}	1.1×10^{-6}	5.4×10^{-10}	1.1×10^{-4}	5.6×10^{-8}	1.0×10^{-6}
Uncontrolled chemical reaction	2.7×10^{-6}	1.1×10^{-9}	5.0×10^{-8}	2.5×10^{-11}	5.2×10^{-6}	2.6×10^{-9}	1.0×10^{-6}
Nuclear criticality	2.5×10^{-3}	1.0×10^{-6}	4.5×10^{-5}	2.3×10^{-8}	6.5×10^{-4}	3.3×10^{-7}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.

Table M.5.3.7.2–3. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Idaho National Engineering Laboratory

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	5.3×10^{-6}	2.1×10^{-9}	4.6×10^{-8}	2.3×10^{-5}	9.9×10^{-5}	4.9×10^{-8}	1.0×10^{-5}
Glovebox fire	5.3×10^{-6}	2.1×10^{-9}	4.6×10^{-8}	2.3×10^{-5}	9.9×10^{-5}	4.9×10^{-8}	1.0×10^{-5}
Glovebox nuclear criticality	3.4×10^{-3}	1.4×10^{-6}	2.7×10^{-5}	2.4×10^{-8}	8.7×10^{-3}	4.3×10^{-6}	1.0×10^{-5}
Calciner feed nuclear criticality	0.034	1.4×10^{-5}	2.7×10^{-4}	1.3×10^{-7}	0.086	4.3×10^{-5}	1.0×10^{-5}
Ceramic can drop	1.3×10^{-10}	5.3×10^{-14}	1.1×10^{-12}	5.7×10^{-16}	2.5×10^{-9}	1.2×10^{-12}	1.0×10^{-3}
Pellet container drop	1.3×10^{-12}	5.3×10^{-16}	1.1×10^{-14}	5.7×10^{-18}	2.5×10^{-11}	1.2×10^{-14}	1.0×10^{-3}
Dissolver spill	6.4×10^{-12}	2.5×10^{-15}	5.5×10^{-14}	2.8×10^{-17}	1.2×10^{-10}	5.9×10^{-14}	0.05
Calciner feed spill	1.9×10^{-11}	7.4×10^{-15}	1.6×10^{-13}	8.0×10^{-17}	3.5×10^{-10}	1.7×10^{-13}	0.05
Calciner product spill	4.6×10^{-9}	1.9×10^{-12}	4.0×10^{-11}	2.0×10^{-14}	8.6×10^{-8}	4.3×10^{-11}	0.05
Sintering furnace explosion	8.0×10^{-5}	3.2×10^{-8}	6.9×10^{-7}	3.4×10^{-10}	1.5×10^{-3}	7.4×10^{-7}	1.0×10^{-6}
Uncontrolled chemical reaction	3.7×10^{-6}	1.5×10^{-9}	3.2×10^{-8}	1.6×10^{-11}	6.9×10^{-5}	3.5×10^{-8}	1.0×10^{-6}
Nuclear criticality	3.4×10^{-3}	1.4×10^{-6}	2.7×10^{-5}	1.3×10^{-8}	8.7×10^{-3}	4.3×10^{-6}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.

Table M.5.3.7.2–4. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Pantex Plant

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	2.3×10^{-6}	9.1×10^{-10}	5.3×10^{-7}	2.6×10^{-10}	1.1×10^{-4}	5.6×10^{-8}	1.0×10^{-5}
Glovebox fire	2.3×10^{-6}	9.1×10^{-10}	5.3×10^{-7}	2.6×10^{-10}	1.1×10^{-4}	5.6×10^{-8}	1.0×10^{-5}
Glovebox nuclear criticality	1.5×10^{-3}	6.2×10^{-7}	4.4×10^{-4}	2.2×10^{-7}	0.019	9.5×10^{-6}	1.0×10^{-5}
Calciner feed nuclear criticality	0.015	6.2×10^{-6}	4.4×10^{-3}	2.2×10^{-6}	0.19	9.5×10^{-5}	1.0×10^{-5}
Ceramic can drop	5.7×10^{-11}	2.3×10^{-14}	1.3×10^{-11}	6.6×10^{-15}	2.8×10^{-9}	1.4×10^{-12}	1.0×10^{-3}
Pellet container drop	5.7×10^{-13}	2.3×10^{-16}	1.3×10^{-13}	6.6×10^{-17}	2.8×10^{-11}	1.4×10^{-14}	1.0×10^{-3}
Dissolver spill	2.7×10^{-12}	1.1×10^{-15}	6.3×10^{-13}	3.2×10^{-16}	1.4×10^{-10}	6.7×10^{-14}	0.05
Calciner feed spill	8.0×10^{-12}	3.2×10^{-15}	1.8×10^{-12}	9.2×10^{-16}	3.9×10^{-10}	2.0×10^{-13}	0.05
Calciner product spill	2.0×10^{-9}	8.0×10^{-13}	4.6×10^{-10}	2.3×10^{-13}	9.8×10^{-8}	4.9×10^{-11}	0.05
Sintering furnace explosion	3.4×10^{-5}	1.4×10^{-8}	8.0×10^{-6}	4.0×10^{-9}	1.7×10^{-3}	8.5×10^{-7}	1.0×10^{-6}
Uncontrolled chemical reaction	1.6×10^{-6}	6.4×10^{-10}	3.7×10^{-7}	1.9×10^{-10}	7.9×10^{-5}	3.9×10^{-8}	1.0×10^{-6}
Nuclear criticality	1.5×10^{-3}	6.2×10^{-7}	4.4×10^{-4}	2.2×10^{-7}	0.019	9.5×10^{-6}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.

Table M.5.3.7.2–5. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Oak Ridge Reservation

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	5.2×10^{-6}	2.1×10^{-9}	9.2×10^{-7}	4.6×10^{-10}	8.0×10^{-4}	4.0×10^{-7}	1.0×10^{-5}
Glovebox fire	5.2×10^{-6}	2.1×10^{-9}	9.2×10^{-7}	4.6×10^{-10}	8.0×10^{-4}	4.0×10^{-7}	1.0×10^{-5}
Glovebox nuclear criticality	3.2×10^{-3}	1.3×10^{-6}	5.8×10^{-4}	2.9×10^{-7}	0.13	6.3×10^{-5}	1.0×10^{-5}
Calciner feed nuclear criticality	0.032	1.3×10^{-5}	5.8×10^{-3}	2.9×10^{-6}	1.3	6.3×10^{-4}	1.0×10^{-5}
Ceramic can drop	1.3×10^{-10}	5.3×10^{-14}	2.3×10^{-11}	1.2×10^{-14}	2.0×10^{-8}	1.0×10^{-11}	1.0×10^{-3}
Pellet container drop	1.3×10^{-12}	5.3×10^{-16}	2.3×10^{-13}	1.2×10^{-16}	2.0×10^{-10}	1.0×10^{-13}	1.0×10^{-3}
Dissolver spill	6.3×10^{-12}	2.5×10^{-15}	1.1×10^{-12}	5.5×10^{-16}	9.6×10^{-10}	4.8×10^{-13}	0.05
Calciner feed spill	1.8×10^{-11}	7.3×10^{-15}	3.2×10^{-12}	1.6×10^{-15}	2.8×10^{-9}	1.4×10^{-12}	0.05
Calciner product spill	4.6×10^{-9}	1.8×10^{-12}	8.1×10^{-10}	4.0×10^{-13}	7.0×10^{-7}	3.5×10^{-10}	0.05
Sintering furnace explosion	7.9×10^{-5}	3.2×10^{-8}	1.4×10^{-5}	6.9×10^{-9}	0.012	6.0×10^{-6}	1.0×10^{-6}
Uncontrolled chemical reaction	3.7×10^{-6}	1.5×10^{-9}	6.5×10^{-7}	3.2×10^{-10}	5.6×10^{-4}	2.8×10^{-7}	1.0×10^{-6}
Nuclear criticality	3.2×10^{-3}	1.3×10^{-6}	5.8×10^{-4}	2.9×10^{-7}	0.13	6.3×10^{-5}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary (1,000 m for this facility at ORR), whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.

Table M.5.3.7.2–6. Immobilized Disposition at the Ceramic Immobilization Facility Accident Impacts at Savannah River Site

	Worker at 1,000 m		Maximum Offsite Individual		Population to 80 km		
Accident Scenario	Dose (rem)	Probability of Cancer Fatality[a]	Dose (rem)	Probability of Cancer Fatality[a]	Dose (person-rem)	Number of Cancer Fatalities[b]	Accident Frequency (per year)
Earthquake	3.7×10^{-6}	1.5×10^{-9}	7.3×10^{-8}	3.6×10^{-11}	3.5×10^{-4}	1.8×10^{-7}	1.0×10^{-5}
Glovebox fire	3.7×10^{-6}	1.5×10^{-9}	7.3×10^{-8}	3.6×10^{-11}	3.5×10^{-4}	1.8×10^{-7}	1.0×10^{-5}
Glovebox nuclear criticality	2.3×10^{-3}	9.1×10^{-7}	4.0×10^{-5}	2.0×10^{-8}	0.041	2.0×10^{-5}	1.0×10^{-5}
Calciner feed nuclear criticality	0.023	9.1×10^{-6}	4.0×10^{-4}	2.0×10^{-7}	0.41	2.0×10^{-4}	1.0×10^{-5}
Ceramic can drop	9.3×10^{-11}	3.7×10^{-14}	1.8×10^{-12}	9.1×10^{-16}	8.8×10^{-9}	4.4×10^{-12}	1.0×10^{-3}
Pellet container drop	9.3×10^{-13}	3.7×10^{-16}	1.8×10^{-14}	9.1×10^{-18}	8.8×10^{-11}	4.4×10^{-14}	1.0×10^{-3}
Dissolver spill	4.5×10^{-12}	1.8×10^{-15}	8.8×10^{-14}	4.4×10^{-17}	4.2×10^{-10}	2.1×10^{-13}	0.05
Calciner feed spill	1.3×10^{-11}	5.2×10^{-15}	2.6×10^{-13}	1.3×10^{-16}	1.2×10^{-9}	6.2×10^{-13}	0.05
Calciner product spill	3.3×10^{-9}	1.3×10^{-12}	6.4×10^{-11}	3.2×10^{-14}	3.1×10^{-7}	1.6×10^{-10}	0.05
Sintering furnace explosion	5.6×10^{-5}	2.2×10^{-8}	1.1×10^{-6}	5.5×10^{-10}	5.3×10^{-3}	2.7×10^{-6}	1.0×10^{-6}
Uncontrolled chemical reaction	2.6×10^{-6}	1.0×10^{-9}	5.1×10^{-8}	2.6×10^{-11}	2.5×10^{-4}	1.2×10^{-7}	1.0×10^{-6}
Nuclear criticality	2.3×10^{-3}	9.1×10^{-7}	4.0×10^{-5}	2.0×10^{-8}	0.041	2.0×10^{-5}	1.0×10^{-6}
[Text deleted.]							

[a] Increased likelihood (or probability) of cancer fatality to a hypothetical individual (a single onsite worker at a distance of 1,000 m or the site boundary, whichever is smaller, or to a hypothetical individual in the offsite population located at the site boundary) if exposed to the indicated dose. The value assumes the accident has occurred.

[b] Estimated number of cancer fatalities in the entire offsite population out to a distance of 80 km if exposed to the indicated dose. The value assumes the accident has occurred.

Note: All values are mean values.

Source: Calculated using the source terms in Tables M.5.3.7.1–3 and M.5.3.7.1–4 and the MACCS computer code.