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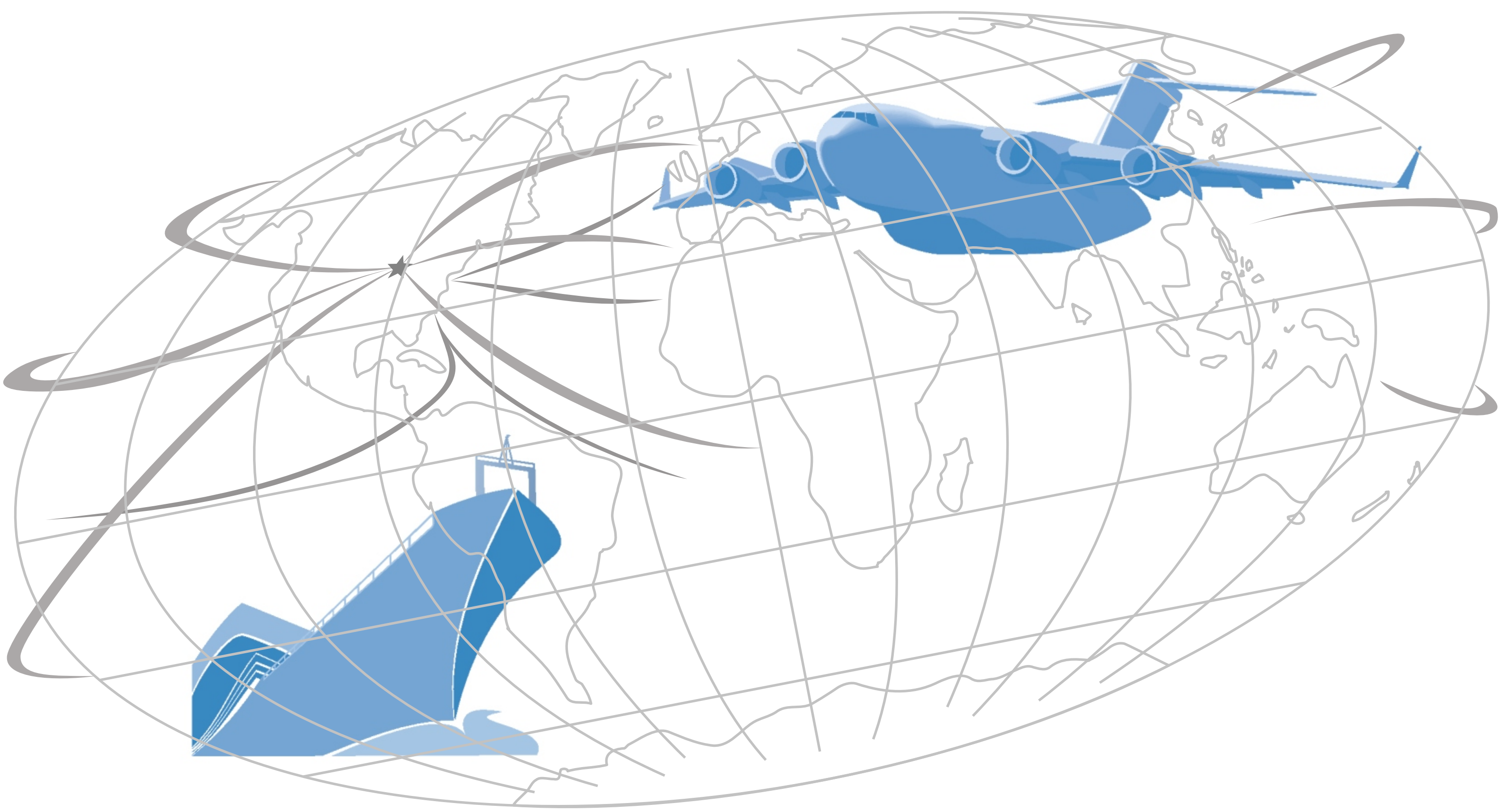
Supplement Analysis for the Air and Ocean Transport of Enriched Uranium between Foreign Nations and the United States



U.S. Department of Energy • National Nuclear Security Administration

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ACRONYMS, ABBREVIATIONS, AND CONVERSION CHARTS

ALARA	as low as reasonably achievable
CoCA	Certificate of Competent Authority
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EA	environmental assessment
EIS	environmental impact statement
FAA	Federal Aviation Agency
FONSI	finding of no significant impact
FR	*Federal Register*
FY	fiscal year
GAO	Government Printing Office
GTRI	Global Threat Reduction Initiative
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
ISO	International Standards Organization
JFK	John F. Kennedy International Airport
LAX	Los Angeles International Airport
LEU	low enriched uranium
LCF	latent cancer fatality
MACCS2	MELCOR Accident Consequence Code System, Revision 2
MEI	maximally exposed individual
NEPA	National Environmental Policy Act of 1969
NNSA	National Nuclear Security Administration
NOAA	National Oceanic Atmospheric Administration
NOI	Notice of Intent
NRC	U.S. Nuclear Regulatory Commission
PEIS	Programmatic Environmental Impact Statement
rem	roentgen equivalent man
ROD	Record of Decision
SA	supplement analysis
SST/SGTs	Safe Secure Transport/Safeguards Transports
TN-BGC1	Transnucléaire shipping container
UO_2	uranium dioxide
U_3O_8	uranium oxide
U.S.	United States
Y-12 Complex	Y-12 National Security Complex

CONVERSIONS

METRIC TO ENGLISH			ENGLISH TO METRIC		
Multiply	**by**	**To get**	**Multiply**	**by**	**To get**
Area					
Square meters	10.764	Square feet	Square feet	0.092903	Square meters
Square kilometers	247.1	Acres	Acres	0.0040469	Square kilometers
Square kilometers	0.3861	Square miles	Square miles	2.59	Square kilometers
Hectares	2.471	Acres	Acres	0.40469	Hectares
Concentration					
Kilograms/square meter	0.16667	Tons/acre	Tons/acre	0.5999	Kilograms/square meter
Milligrams/liter	1 [a]	Parts/million	Parts/million	1 [a]	Milligrams/liter
Micrograms/liter	1 [a]	Parts/billion	Parts/billion	1 [a]	Micrograms/liter
Micrograms/cubic meter	1 [a]	Parts/trillion	Parts/trillion	1 [a]	Micrograms/cubic meter
Density					
Grams/cubic centimeter	62.428	Pounds/cubic feet	Pounds/cubic feet	0.016018	Grams/cubic centimeter
Grams/cubic meter	0.0000624	Pounds/cubic feet	Pounds/cubic feet	16,025.6	Grams/cubic meter
Length					
Centimeters	0.3937	Inches	Inches	2.54	Centimeters
Meters	3.2808	Feet	Feet	0.3048	Meters
Kilometers	0.62137	Miles	Miles	1.6093	Kilometers
Temperature					
Absolute					
Degrees C + 17.78	1.8	Degrees F	Degrees F - 32	0.55556	Degrees C
Relative					
Degrees C	1.8	Degrees F	Degrees F	0.55556	Degrees C
Velocity/Rate					
Cubic meters/second	2118.9	Cubic feet/minute	Cubic feet/minute	0.00047195	Cubic meters/second
Grams/second	7.9366	Pounds/hour	Pounds/hour	0.126	Grams/second
Meters/second	2.237	Miles/hour	Miles/hour	0.44704	Meters/second
Volume					
Liters	0.26418	Gallons	Gallons	3.78533	Liters
Liters	0.035316	Cubic feet	Cubic feet	28.316	Liters
Liters	0.001308	Cubic yards	Cubic yards	764.54	Liters
Cubic meters	264.17	Gallons	Gallons	0.0037854	Cubic meters
Cubic meters	35.314	Cubic feet	Cubic feet	0.028317	Cubic meters
Cubic meters	1.3079	Cubic yards	Cubic yards	0.76456	Cubic meters
Cubic meters	0.0008107	Acre-feet	Acre-feet	1233.49	Cubic meters
Weight/Mass					
Grams	0.035274	Ounces	Ounces	28.35	Grams
Kilograms	2.2046	Pounds	Pounds	0.45359	Kilograms
Kilograms	0.0011023	Tons (short)	Tons (short)	907.18	Kilograms
Metric tons	1.1023	Tons (short)	Tons (short)	0.90718	Metric tons
ENGLISH TO ENGLISH					
Acre-feet	325,850.7	Gallons	Gallons	0.000003046	Acre-feet
Acres	43,560	Square feet	Square feet	0.000022957	Acres
Square miles	640	Acres	Acres	0.0015625	Square miles

a. This conversion is only valid for concentrations of contaminants (or other materials) in water.

METRIC PREFIXES

Prefix	Symbol	Multiplication factor
exa-	E	1,000,000,000,000,000,000 = 10^{18}
peta-	P	1,000,000,000,000,000 = 10^{15}
tera-	T	1,000,000,000,000 = 10^{12}
giga-	G	1,000,000,000 = 10^{9}
mega-	M	1,000,000 = 10^{6}
kilo-	k	1,000 = 10^{3}
deca-	D	10 = 10^{1}
deci-	d	0.1 = 10^{-1}
centi-	c	0.01 = 10^{-2}
milli-	m	0.001 = 10^{-3}
micro-	µ	0.000 001 = 10^{-6}
nano-	n	0.000 000 001 = 10^{-9}
pico-	p	0.000 000 000 001 = 10^{-12}

EXECUTIVE SUMMARY

The United States (U.S.) Department of Energy (DOE), National Nuclear Security Administration (NNSA) has prepared this Supplement Analysis (SA) for the air and ocean transport of enriched uranium between foreign nations and the United States to provide information and analysis to determine whether or not a supplement to the *Final Site-Wide Environmental Impact Statement for the Y-12 National Security Complex (Y-12 Site-Wide EIS)* (DOE 2001) or a new environmental impact statement (EIS) is required. This SA evaluates the environmental impacts associated with the air or sea transportation of up to 5,000 kilograms (11,000 pounds) of enriched uranium over a 10-year period from foreign countries to the Y-12 National Security Complex (Y-12 Complex) near Oak Ridge, Tennessee (the Proposed Action). Transport modes include military and commercial air cargo and ocean vessel. All shipments are assumed to meet International Atomic Energy Agency (IAEA) specifications for unirradiated uranium and Y-12 Complex acceptance criteria.

This SA evaluates the environmental impacts of incident-free (normal operation) air and sea transport, as well as the environmental impacts of postulated accidents. The impacts are presented in terms of radiological consequences (doses) and risks (latent cancer fatalities [LCFs]) to the aircraft crew, cargo handlers, ship crew, noninvolved workers, and the public. Key radiological consequences and risks for an air shipment are summarized in the table below. The environmental impacts of sea transport of enriched uranium are bounded by previous analyses of sea transport of enriched uranium and foreign research reactor spent nuclear fuel.

Dose Receptor (scenario)	*Radiation Dose (person-rem)*	*Risk (LCF)* [a]	*Air Flight Cosmic Radiation Dose and Risk (person-rem/LCF)*
Single Military Air Shipment of Unirradiated Enriched Uranium			
Aircrew member (normal operations), 100 kilograms	5.1×10^{-4}	3.1×10^{-7}	1.5×10^{-2} / 9×10^{-6}
Ground cargo handler (normal operations), 100 kilograms	2.8×10^{-3}	1.7×10^{-6}	Not applicable
Non-involved worker (accident), 100 kilograms	0.113	1.08×10^{-10}	Not applicable
MEI (accident), 100 kilograms	7.04×10^{-4}	6.75×10^{-13}	Not applicable
50-mile population (accident), 100 kilograms	38.5	3.70×10^{-8}	Not applicable
Single Commercial Air Transport of Unirradiated Enriched Uranium			
Aircrew member (normal operations), 5 kilograms	2.8×10^{-4}	1.7×10^{-7}	1.4×10^{-2} / 8.64×10^{-6}
Ground cargo handler (normal operations), 5 kilograms	2.3×10^{-4}	1.4×10^{-7}	Not applicable
Non-involved worker (accident), 10 kilograms	0.0113	1.90×10^{-12}	Not applicable
MEI (accident), 10 kilograms	7.04×10^{-5}	1.18×10^{-14}	Not applicable
50-mile population (accident), 10 kilograms	9.01	1.51×10^{-9}	Not applicable

LCF = latent cancer fatality, MEI = maximally exposed individual, rem = roentgen equivalent man.

[a] Normal operations risk uses a probability of 1, whereas military air transport accident risk includes a probability of 1.6×10^{-6} per operation and commercial air transport accident risk includes a probability of 2.8×10^{-7} per operation.

Note: To convert kilograms to pounds, multiply by 2.2.

The normal operation crew radiation doses are a small fraction of the additional radiation dose they would receive from cosmic radiation during the flights. The cargo handler radiation dose is also a small fraction of normal background annual radiation dose. Appendix A presents a method to calculate the normal operations and accident radiological consequences for a specific air shipment to the Y-12 Complex.

This SA shows that the environmental impacts to workers and the public from the Proposed Action are very small. These results are consistent with previous environmental impact analyses of transportation of enriched uranium from foreign countries to the Y-12 Complex. In conclusion, NNSA has determined that the continued acceptance of enriched uranium at the Y-12 Complex in quantities up to 5,000 kilograms (11,000 pounds) from foreign countries is not a substantial change in the Proposed Action that is relevant to environmental concerns and does not represent significant new circumstances or information relevant to environmental concerns and bearing on the Proposed Action or its impacts. Therefore, no supplement to the *Y-12 Site-Wide EIS* needs to be prepared and no additional transportation analyses are expected to be required for future shipments during the next 10 years.

1.0 INTRODUCTION AND PURPOSE AND NEED FOR AGENCY ACTION

The United States (U.S.) Department of Energy (DOE) National Nuclear Security Administration (NNSA) has prepared this Supplement Analysis (SA) for the air and ocean transport of enriched uranium between foreign nations and the United States pursuant to the National Environmental Policy Act (NEPA). It evaluates the environmental impacts associated with transport of enriched uranium from foreign countries to the NNSA Y-12 National Security Complex (Y-12 Complex) in Oak Ridge, Tennessee (the Proposed Action). The purpose of this SA is to determine whether or not the *Final Site-Wide Environmental Impact Statement for the Y-12 National Security Complex (Y-12 Site-Wide EIS)* (DOE 2001) and other NEPA documents adequately encompass the environmental effects of the Proposed Action and whether or not the EIS should be supplemented, a new EIS should be prepared, or no further NEPA documentation is required.

1.1 Background

Through the *Global Threat Reduction Initiative* (GTRI) and other defense programs, DOE is working with international partners to secure and remove high-risk nuclear and radiological materials that pose a threat to the United States and the international community. Although significant strides have been made in improving the security of hundreds of tons of weapons-usable material in Russia, significant quantities of nuclear materials still exist in dozens of research reactors and other locations throughout the world. Key efforts under GTRI (and earlier initiatives) include the conversion of research reactors from highly enriched uranium (HEU)[1] to low enriched uranium (LEU) fuels and the repatriation of HEU fuel to the country of origin (U.S. or Russia) or other appropriate disposition paths to eliminate the HEU in civil commerce.

This SA addresses certain transportation activities that are part of the transfer of HEU (and in some cases LEU) to the U.S. Under the proposed action, up to 5 metric tons[2] (5,000 kilograms or 11,000 pounds) of unirradiated enriched uranium may be transported to the Y-12 Complex (for temporary storage and disposition) from several different countries over a period of 10 years. Some individual shipments have already been received at the Y-12 Complex and were addressed in earlier NEPA analyses.

1.2 Purpose and Need for the Supplement Analysis

While these types of shipments have occurred in the past, and have been addressed in other NEPA documents, this SA has been prepared to address those elements of transportation for future shipments of HEU to the Y-12 Complex that have not already been addressed under the *Y-12 Site-Wide EIS* and other related NEPA documents – namely, (1) air transport over the global commons and U.S. territory to the port of entry, and (2) transfer at the airport of entry to a ground transportation vehicle. This SA describes the Proposed Action, references other transportation activities already covered by existing NEPA documents (e.g., transport by ocean vessel), and identifies and analyzes the impacts of those elements not addressed specifically in earlier NEPA documents.

[1] *Highly enriched uranium is frequently called high-enriched uranium. The International Atomic Energy Agency (IAEA) Safeguards Glossary defines high-enriched uranium as uranium containing 20 percent or more of the isotope uranium-235 [by weight]. It defines low enriched uranium as enriched uranium containing less than 20 percent of the isotope uranium-235 [by weight] (IAEA 2002).*

[2] *One metric ton equals 1,000 kilograms or 2,200 pounds.*

Based on analyses in the *Y-12 Site-Wide EIS* and other NEPA documents (see Section 1.4), the Y-12 Complex is authorized to safely store up to 500 metric tons (500,000 kilograms or 1,100,000 pounds) of HEU, including 5 metric tons (5,000 kilograms or 11,000 pounds) of HEU from foreign countries, and 6 metric tons (6,000 kilograms or 13,200 pounds) of LEU from various sources.

Environmental impacts associated with transportation of HEU from foreign countries to the United States have been addressed in separate NEPA actions, including the following:

- *Environmental Assessment for the Proposed Interim Storage at the Y-12 Plant Oak Ridge, Tennessee of Highly Enriched Uranium Acquired from Kazakhstan by the United States (Project Sapphire EA)* (DOE 1994);

- *Environmental Assessment for the Transportation of Highly Enriched Uranium from the Russian Federation to the Y-12 National Security Complex and Finding of No Significant Impact (Russian HEU Transport EA)* (DOE 2004a); and

- *Environmental Assessment for the Transportation of Unirradiated Uranium in Research Reactor Fuel from Argentina, Belgium, Japan, and the Republic of Korea to the Y-12 National Security Complex (Foreign Reactor Fuel EA)* (DOE 2005a).

These environmental assessments (EAs) all determined that the proposed shipments would not constitute major federal actions significantly affecting the quality of the environment (see Section 1.4.2). Based on these determinations, and because additional shipments are expected in the future, DOE decided to prepare this SA to the *Y-12 Site-Wide EIS* to address all shipments of HEU that could be authorized, considering the existing storage limit for foreign HEU. Preparation of this SA facilitates more efficient procedures for receipt of enriched uranium and safe disposition of excess nuclear materials. Although most shipments would utilize commercial or military aircraft, as appropriate, some shipments may be made by ocean vessel, particularly as co-shipments with spent nuclear reactor fuel from foreign research reactors.

1.3 Proposed Action and Scope

Proposed Action

The Proposed Action is to continue the transport of enriched uranium (HEU or LEU) between locations in foreign countries and the United States, where enriched uranium transported to the United Stated would continue to be temporarily stored at the Y-12 Complex pending its further disposition. The Proposed Action is a necessary component of DOE's GTRI and other defense programs. The amount of HEU and LEU stored at the Y-12 Complex would remain within quantities authorized for storage through consideration of previous NEPA analyses. Transportation modes (air cargo, ocean vessel, ground vehicles) would also be consistent with those modes considered in previous NEPA analyses.

Scope

This SA addresses the environmental impacts from transporting enriched uranium in various forms (including unirradiated research reactor fuel) over the global commons by commercial or military air transport to selected airports of entry in the United States. It also addresses the environmental impacts of transport of the enriched uranium by ocean vessel. The global commons refers to that portion of the earth that is not under the jurisdiction of any specific nation, such as the oceans of the world, and, for this SA, includes the international airspace that would be traversed by transport aircraft. This SA also evaluates the transfer of the uranium to ground transportation vehicles.

The scope of this SA is limited to the assumed transportation of up to 5 metric tons (5,000 kilograms or 11,000 pounds) of enriched uranium to the Y-12 Complex over a period of approximately 10 years. This enriched uranium is expected to consist primarily of HEU, although some quantities of LEU may be transported. Transportation of the enriched uranium would be in accordance with international and Federal requirements and procedures for safety and security and for management of possible emergencies. The international basis for radioactive material transport has been established by the International Atomic Energy Agency (IAEA). Additional requirements within this overall framework have been implemented by international and national regulatory and trade organizations. International organizations include the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA), and the International Maritime Organization (IMO). National organizations within the United States include DOE, the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Transportation (DOT).

NNSA is working with its international partners in global nonproliferation to identify future shipments of enriched uranium to the U.S. from foreign countries. It is not known at this time what specific countries and under what timeframes these shipments will occur (other than that they will be over the next 10 years and will not exceed 5 metric tons [5,000 kilograms or 11,000 pounds] of enriched uranium). Therefore, this SA considers hypothetical shipment information that provides a bounding case for analysis of impacts.

The activities involved in transporting the enriched uranium and the responsibility for assessing environmental impacts are identified in **Table 1–1**. Where a transportation activity is already covered by an existing NEPA document, the table identifies that document.

Table 1–1 Addressing Environmental Impacts of Transport of Unirradiated Highly Enriched Uranium

Activity	*Environmental Impacts Assessed by:*
Packaging and transport from nuclear facility to departure site	Participating nuclear facility and host countries
Transport over the territory of foreign countries	Not required [a]
Transport over the global commons and U.S. territory to the port of entry	This SA for air transport The *FRR SNF EIS* [b] and *Russian HEU Transport EA* [c] for ship transport
Transfer at the port of entry to a ground transportation vehicle	This SA for air transport The *FRR SNF EIS* [b] and *Russian HEU Transport EA* [c] for ship transport
Ground transportation from port of entry to the Y-12 Complex	*Y-12 Site-Wide EIS* [d] and *Y-12 Interim Storage EA* [e]
Management at the Y-12 Complex	*Y-12 Site-Wide EIS* [d] and *Y-12 Interim Storage EA* [e]

[a] Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*, January 4, 1979.
[b] *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel (FRR SNF EIS)* (DOE 1996a).
[c] *Environmental Assessment for the Transportation of Highly Enriched Uranium from the Russian Federation to the Y-12 National Security Complex and Finding of No Significant Impact (Russian HEU Transport EA)* (DOE 2004a).
[d] *Final Site-Wide Environmental Impact Statement for the Y-12 National Security Complex (Y-12 Site-Wide EIS)* (DOE 2001). It is currently being revised.
[e] *Environmental Assessment for Proposed Interim Storage of Enriched Uranium Above the Maximum Historical Storage Level of the Y-12 Plant (Y-12 Interim Storage EA)* (DOE 1995b).

The following discussion expands on the information contained in Table 1–1.

Foreign Country Activities. Packaging of the nuclear material at foreign nuclear facilities and transportation to the location at which the United States takes possession would be the responsibility of the countries from which the nuclear material is received. It is assumed that transportation activities within the foreign country would meet applicable local and international rules and regulations. Therefore, this SA does not evaluate the impacts of actions taken in the foreign countries to prepare the nuclear material for shipment, the impacts of shipping the nuclear material to points of departure to the United States, or the impacts of transport over the territory of foreign countries.

Transport by Ocean Vessel. Enriched uranium potentially transported by ocean vessel over the global commons to a U.S. port of entry may or may not be combined with shipments of spent nuclear reactor fuel from foreign countries. Because ocean transport of enriched uranium to the U.S. has already been addressed in existing NEPA documents, this SA does not provide an independent assessment of ocean vessel transport of enriched uranium but references these existing documents. The *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (*FRR SNF EIS*) (DOE 1996a) addressed the environmental impacts of a proposed policy for U.S. acceptance of spent nuclear fuel from research reactors from several foreign countries. The May 17, 1996 Record of Decision (ROD) for that policy indicated that unirradiated fuel (HEU or LEU) from eligible research reactors would be accepted as spent nuclear fuel (61 Federal Register [FR] 25091). The *Russian HEU Transport EA* (DOE 2004a) addressed the environmental impacts from ocean (or air) transport to the U.S. of up to 166 kilograms (365 pounds) of HEU per shipment (see Section 1.4.2).

Transport by Air. Transportation over the global commons and U.S. territory by air to a U.S. port of entry is addressed in this SA. In accordance with DOE requirements and policies, it is assumed that commercial air shipment would be restricted to DOE Category III and IV quantities of special nuclear material (IAEA Category II and III). The largest quantity of HEU shipped by commercial carrier would normally be 5 kilograms (11 pounds). DOE Category I and II quantities of special nuclear material (IAEA Category I) would be shipped by military air transport. It is expected that most shipments would not exceed 50 kilograms (110 pounds) of HEU, although shipments up to 100 kilograms (220 pounds) may occur.

Ground Transport to Y-12 and Activities at Y-12. This SA analysis extends to the time when trucks are loaded with the packages of enriched uranium for transport to the Y-12 Complex. Transportation to and activities that would occur at the Y-12 Complex, such as unloading the uranium, transferring it to a storage location, and monitoring it while in storage, are within the scopes of the *Y-12 Interim Storage EA* (DOE 1995b) and the *Y-12 Site-Wide EIS* (DOE 2001). (See Section 1.4.1.) Because the previously authorized storage limits for enriched uranium would be retained, there would be neither nuclear material shipments nor Y-12 Complex activities that have not been previously analyzed. Hence, overland transport and Y-12 Complex activities involving the enriched uranium are not addressed in this SA.

1.4 Related National Environmental Policy Act Documentation

DOE has prepared several NEPA documents to support decisions about the long-term storage and disposition of fissile material, the maintenance of national security, and reliability of the nuclear weapons stockpile. “Higher-tier” NEPA documents, such as programmatic environmental impact statements (PEISs), address programmatic requirements and are designed to support and implement the Y-12-related decisions made by DOE as supported by lower-tier NEPA documents, including environmental impact statements (EISs) and EAs.

1.4.1 National Environmental Policy Act Analyses Related to Highly Enriched Uranium Storage and Ground Transport at the Y-12 Complex

The *Y-12 Interim Storage EA* (DOE 1995b) assessed the continued interim storage of enriched uranium at Y-12, with an increase in the amount of material stored above the historical maximum level. That EA was integrated into the *Y-12 Site-Wide EIS* (DOE 2001) "tiering" NEPA review (i.e., preparation of site-specific analysis concentrating on the issues specific to implementing decisions made in broader PEISs). The EA addressed receipt and storage of up to 500 metric tons (550 tons) of HEU, including up to 5 metric tons (5.5 tons) of HEU from foreign countries. The EA also addressed receipt and storage of up to 7,105.9 metric tons (7,810 tons) of LEU. However, DOE determined that the Y-12 Complex would store no more than 500 metric tons (550 tons) of HEU and 6 metric tons (6.6 tons) of LEU at the Y-12 Complex,[3] and that such storage would not constitute a major Federal action significantly affecting the quality of the human environment (60 FR 54068).

In 1996, DOE arrived at a programmatic decision regarding the storage location of HEU. The *Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement (S&D EIS)* (DOE 1996b) included an evaluation of programmatic alternatives for providing secure storage of fissile materials. The scope of the analysis included storage of 994 metric tons of HEU. Subsequently, on January 21, 1998, DOE issued a Record of Decision that named the Y-12 Complex as the central repository for storage of HEU (62 FR 3014). That decision confirmed and extended the uranium storage mission at the Y-12 Complex beyond the 10 years assessed in the *Y-12 Interim Storage EA*.

The *Y-12 Site-Wide EIS* (DOE 2001) evaluated the impacts associated with various levels of operational activities. The scope of that EIS included Y-12 Complex support to NNSA's Nuclear Nonproliferation and National Security Program. On March 13, 2002, DOE announced its decision to implement its "planning basis" alternative to meet mission requirements, which included storage of HEU and the construction of two new facilities at the Y-12 Complex – the HEU Materials Facility (for storage of HEU) and the Special Materials Complex (67 FR 11296).[4] The *Y-12 Site-Wide EIS* addressed onsite activities associated with HEU, including ground transport by truck and the receipt, unloading, and transfer of HEU into storage. The quantities of HEU (and LEU) addressed in that EIS are consistent with those previously authorized by DOE (60 FR 54068). NNSA issued a Federal Register Notice on November 28, 2005, of a Notice of Intent (NOI) to prepare a new site-wide EIS for the Y-12 National Security Complex (70 FR 71270).

1.4.2 National Environmental Policy Act Analyses Related to Transportation and to this Supplemental Analysis

The *FRR SNF EIS* (DOE 1996a) evaluated the environmental impacts that could result from a joint proposal by DOE and the Department of State to adopt a policy for the U.S. to accept and manage spent nuclear fuel, including unirradiated HEU and LEU, from eligible foreign research reactors. The scope of the *FRR SNF EIS* included the receipt of foreign research reactor spent nuclear fuel at one or more U.S. marine ports of entry, overland transport to one or more DOE sites, and management of the spent nuclear fuel (interim storage and ultimate disposition) in the U.S.

The *FRR SNF EIS* analysis of environmental impacts associated with ship transport of spent nuclear fuel bounds the environmental impacts associated with ship transport of unirradiated HEU and LEU. Possible environmental impacts from incident-free transportation were considered in the *FRR SNF EIS*, as well as possible impacts from accidents, including extreme accidents such as the sinking of the ocean vessel at sea and a ship fire at the port of entry. The analysis considered up to 371 shipments over several years, with the largest voyage duration being 34 days and the average being 21 days. DOE prepared and implemented a Mitigation Action Plan to ensure that no crewmember would receive more than the

[3] At the time the finding of no significant impact (FONSI) was issued, the Y-12 Complex was already storing 3 metric tons of LEU; therefore, an additional 3 metric tons could be received (60 FR 54068).
[4] At the time the Y-12 Site-Wide EIS was prepared, the Y-12 Complex used six separate buildings for storage of HEU. Construction of the Special Materials Complex was subsequently cancelled.

maximum allowed radiation dose under the regulatory limits established for the general public (100 millirem in a year) (61 FR 25100).

A 1998 Supplement Analysis for the *FRR SNF EIS* addressed: (1) the acceptance of foreign research spent nuclear fuel from research reactors not specifically mentioned in the EIS (but within the set of countries considered in the EIS); (2) the acceptance of spent nuclear fuel in quantities larger than those estimated for a specific reactor or country in the EIS; and (3) the transport of more than eight casks of spent nuclear fuel on a single ocean-going vessel. The 1998 Supplement Analysis determined that these actions would not constitute significant new circumstances or information relative to environmental concerns (DOE 1998). A 2004 Supplement Analysis addressed: (1) extending the expiration date for irradiation of eligible spent nuclear fuel by either 5 or 10 years; (2) extending the acceptance date for eligible spent nuclear fuel by either 5 or 10 years; and (3) expending eligibility to an Australian reactor for participation in the spent nuclear fuel acceptance program. That 2004 Supplement Analysis determined that extending the expiration and acceptance dates by up to 10 years (to May 12, 2016 and May 12, 2019, respectively), and accepting the Australian fuel, would not constitute significant new circumstances or information relative to environmental concerns (DOE 2004c).[5]

The *Project Sapphire EA* (DOE 1994) evaluated the environmental impacts of transporting 566 kilograms (1,250 pounds) of HEU contained in 2,200 kilograms (4,840 pounds) of material from Kazakhstan to the Y-12 Complex. The assessment's scope included transport by military aircraft over the global commons to an aerial port of entry, transfer from the aircraft to Safe Secure Transport/Safeguards Transport vehicles (SST/SGTs), ground transportation by SST/SGTs, and transfer from the SST/SGTs to the Y-12 Complex. DOE made a FONSI associated with air-land transportation of the Kazakhstan HEU (DOE 1995a).[6]

The *Russian HEU Transport EA* (DOE 2004a) evaluated the environmental impacts associated with the transfer of an average of 166 kilograms (365 pounds) per year, over a period of 10 years, of HEU from Russia to the NNSA Y-12 Complex. Transportation modes included in this analysis were military aircraft or ship transport[7] combined with ground transport by truck. DOE found that the shipment of the Russian HEU would not constitute a major federal action significantly affecting the quality of the environment.[8]

The *Foreign Reactor Fuel EA* (DOE 2005a) evaluated the environmental impacts associated with the transfer of unirradiated nuclear reactor fuel from four foreign countries to the United States. The total uranium mass to be shipped from each of the four countries ranged from 1.9 to 15.2 kilograms (4.2 to 33.5 pounds). Transportation modes included in the analysis were commercial air cargo and military air transport. DOE found that the actions contemplated in the EA would not constitute a major federal action significantly affecting the quality of the environment (DOE 2005b).[9]

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[5] *Because the U.S. policy remains to accept HEU and LEU as part of the foreign research reactor spent nuclear fuel acceptance program, the determinations pertaining to the specificity of the research reactors eligible for the program, and the dates of fuel acceptance, would also apply to HEU and LEU accepted as part of the program.*

[6] *This material was received at the Y-12 Complex and temporary stored. It has since been relocated from the Y-12 Complex.*

[7] *The analyses in the Russian HEU Transport EA, which addressed the option of shipping 166 kilograms of HEU on a 21-day sea voyage to the United States, considered impacts from normal transport and accidents (DOE 2004a). The radiation dose to a member of the vessel crew from shipment of this material was 1-to-2 millirem, which was smaller than the crew doses estimated in the FRR SNF EIS for a voyage of identical length. The dose assessed in the Russian HEU Transport EA to persons unloading the HEU and placing it into trucks was also smaller than that assessed in the FRR SNF EIS for unloading two spent nuclear fuel casks from a vessel assuming maximum dose rates permitted for exclusive-use transport. (A vessel may carry eight or more casks.) The risks from an accident were also smaller. The conclusion was that shipment of the HEU by air or by ship would not constitute a major federal action affecting the quality of the environment.*

[8] *Shipment of this material has not yet occurred.*

[9] *Shipment of this material is in progress. Shipment of the Belgium and Argentina fuel have occurred.*

2.0 ANALYSIS DESCRIPTION AND ASSUMPTIONS

One of the purposes of DOE's GTRI is to implement the United States' nonproliferation policy of minimizing and, to the extent possible, eliminating the use of HEU in worldwide nuclear programs.[10] The most common civilian use of HEU is for fuel and targets in research and test reactors. The United States is working with many international partners to secure HEU and LEU and, where appropriate for U.S. acceptance, transfer it to NNSA's Y-12 Complex.

2.1 Overview of Shipment Contents

Enriched uranium may be transported to the Y-12 Complex from several different countries in a variety of physical and chemical forms and configurations. For example, shipments of enriched uranium as nuclear fuel may be in the form of plates or rods, as individual units, or as assemblies. Fuel cladding may be aluminum or stainless steel, or another material, and the core may be a uranium-aluminum alloy or a uranium-zirconium hydride, among other physical and chemical matrices. Shipments of enriched uranium may be in forms other than fuel, such as uranium dioxide (UO_2) or uranium oxide (U_3O_8) in pellet or powder form.

The quantity of enriched uranium to be transported in any shipment, and from any foreign country, may vary. However, for this SA it was assumed that 5 metric tons (5,000 kilograms, or 11,000 pounds) of HEU from foreign countries would be shipped to the Y-12 Complex over a period of 10 years. Some quantities of LEU may accompany the HEU.

Although the enrichment of the transported uranium may vary, an enrichment of 93.5 percent uranium-235 was assumed for this SA, in the chemical form of uranium oxide powder. The assumed isotopic mass and activity of uranium-234, uranium-235, and uranium-238 are presented in **Table 2–1** for example shipments of 10 and 100 kilograms (22 to 220 pounds) of HEU.

Table 2–1 Assumed Uranium Isotope Distributions

Isotope	*10-Kilogram HEU Shipment* [a]		*100-Kilogram HEU Shipment* [a]	
	Mass (grams)	*Activity (curies)*	*Mass (grams)*	*Activity (curies)*
Uranium-234	64.3	0.405	643	4.05
Uranium-235	7,929	0.0171	79,288	0.171
Uranium-238	451	0.00017	4,513	0.0017

HEU = highly enriched uranium.
[a] The HEU was conservatively assumed to be in the form of uranium oxide (U_3O_8) powder.
Note: To convert grams to pounds, divide by 454.

The enriched uranium received at the Y-12 Complex would meet the most limiting requirements of either the Y-12 Complex acceptance criteria or the Certificate of Competent Authority (CoCA) of the shipping packaging (see Section 2.2). A CoCA will typically state whether the packaging will allow materials having some neutron irradiation history or simply require that the shipped material be unirradiated. As that term is defined by the IAEA, unirradiated uranium is uranium containing not more than 2×10^3 becquerels (5.4×10^{-8} curies) of plutonium per gram of uranium-235, not more than 9×10^6 becquerels (2.4×10^{-4} curies) of fission products per gram of uranium-235, and not more than 5×10^{-3} grams of

[10] *In addition to addressing HEU, the GTRI addresses other nuclear materials such as LEU.*

uranium-236 per gram of uranium-235 (IAEA 2005). The applicable Y-12 Complex acceptance criteria are summarized in **Table 2–2**.

Table 2–2 Applicable Y-12 Complex Acceptance Criteria for Shipments of Enriched Uranium

Parameter	*Acceptance Criteria*
Photon exposure, enriched uranium Total mass per container or part less than 1 kilogram	Less than or equal to 2 milliRoentgen per hour per kilogram of uranium at 1 foot from the package surface
Photon exposure, enriched uranium Total mass per container or part greater than or equal to 1 kilogram	Less than or equal to 2 milliRoentgen per hour at 1 foot from the package surface
Deep dose (gamma + neutron dose) Total mass per container or part less than 1 kilogram	Less than or equal to 2 millirem per hour per kilogram of uranium at 1 foot from the package surface
Deep dose (gamma + neutron dose) Total mass per container or part greater than or equal to 1 kilogram	Less than or equal to 2 millirem per hour at 1 foot from the package surface

Note: For photon exposure, 1 milliRoentgen per hour is equal to 1 millirem per hour. To convert kilogram to pounds, multiply by 2.2; meters to feet, multiply by 3.3.

For this SA, the enriched uranium is assumed to meet the IAEA definition of unirradiated uranium. Enriched uranium that meets the IAEA definition will also meet the Y-12 Complex acceptance criteria.

2.2 Overview of Transport Packaging

The enriched uranium would be placed in Type A or Type B packaging, as appropriate, in compliance with United States and international standards for safe transportation of radioactive materials. These standards include IAEA Safety Standard Series No. TS-R-1, *Regulations for the Safe Transport of Radioactive Material* (IAEA 2005), and 10 CFR 71, *Nuclear Regulatory Commission Regulations for Packaging and Transportation of Radioactive Materials*. Type A packages must be designed and tested to withstand the conditions of normal transport. A quantity of radioactive material larger than a Type A quantity is defined as a Type B quantity. Type B packages must be designed and tested to withstand the conditions of normal transport as well as accident conditions.[11] Most packages that would be used for HEU transport are expected to be Type B packages.

Compliance with applicable packaging regulations for structural integrity, containment assurance, and maintenance of subcriticality is assured through an international program of package certification of compliance by a Competent Authority. Minimum standards for package performance established by the IAEA have been adopted as requirements by the United States and other nations. In the United States, Type B packages are approved for use by NRC and DOT.[12] The approving agency issues Certificates of Compliance for packages designed and tested to meet requirements set forth in their respective regulations and requirements. NRC and DOT requirements for Type B packages are essentially the same. Packages certified by the competent licensing authority of a foreign nation may be used provided that the package has been revalidated by DOT, with technical assistance from the NRC, and that it receives a CoCA.

[11] *Normal transport conditions, which may result in a package being subjected to heat, cold, vibration, changes in pressure, or other possible occurrences (e.g., being dropped, compressed under a weight, sprayed with water, or struck by objects) must not result in loss of function (e.g., containment, shielding, continuance of subcriticality). Hypothetical accident tests simulate the effects of severe accidents. There must be no substantial loss of function of the package even after being subject to a series of tests that are conducted sequentially. These tests simulate being dropped from a height; being crushed or punctured; being exposed to a high heat (a temperature of at least 800º C or 1,472º F), as from a fire, for 30 minutes; or immersion in water.*

[12] *DOE approves the use of packages for shipment of defense nuclear materials.*

Selection of the Type B packages to be used for a particular shipment would depend on the physical requirements for accommodating the material and the availability of the packaging. Typical Type B packages currently include the Transnucléaire shipping container (TN-BGC1) (**Figure 2–1**), the DOE/NNSA shipping container (ES-2100) (**Figure 2–2**), and the BWX Technologies shipping container (5X22) (**Figure 2–3**). Type B packages would be used in compliance with the requirements of the applicable Competent Authority certification that establishes limits on the amount of fissile material allowed in each package. As an example, the TN-BGC1 package has a single-package-limit of 7 kilograms (15.4 pounds) of uranium-235 in the form of an aluminum alloy (DOT 2006). Future packaging use may include the ES-3100 package. This package is currently certified for transport of up to 33 kilograms (108 pounds) of HEU overland. The NNSA is planning to submit an amendment in 2007 for recertifying ES-3100 packages for transport by air. (When certified for air transport, the ES-3100 will probably have the same 7 kilograms [15.4 pounds] uranium-235 limit as that for the TN-BGC1 package.) The physical size and configuration of the individual components comprising the enriched uranium shipments may have a greater influence on the number of containers used for each shipment than the uranium-235 content.

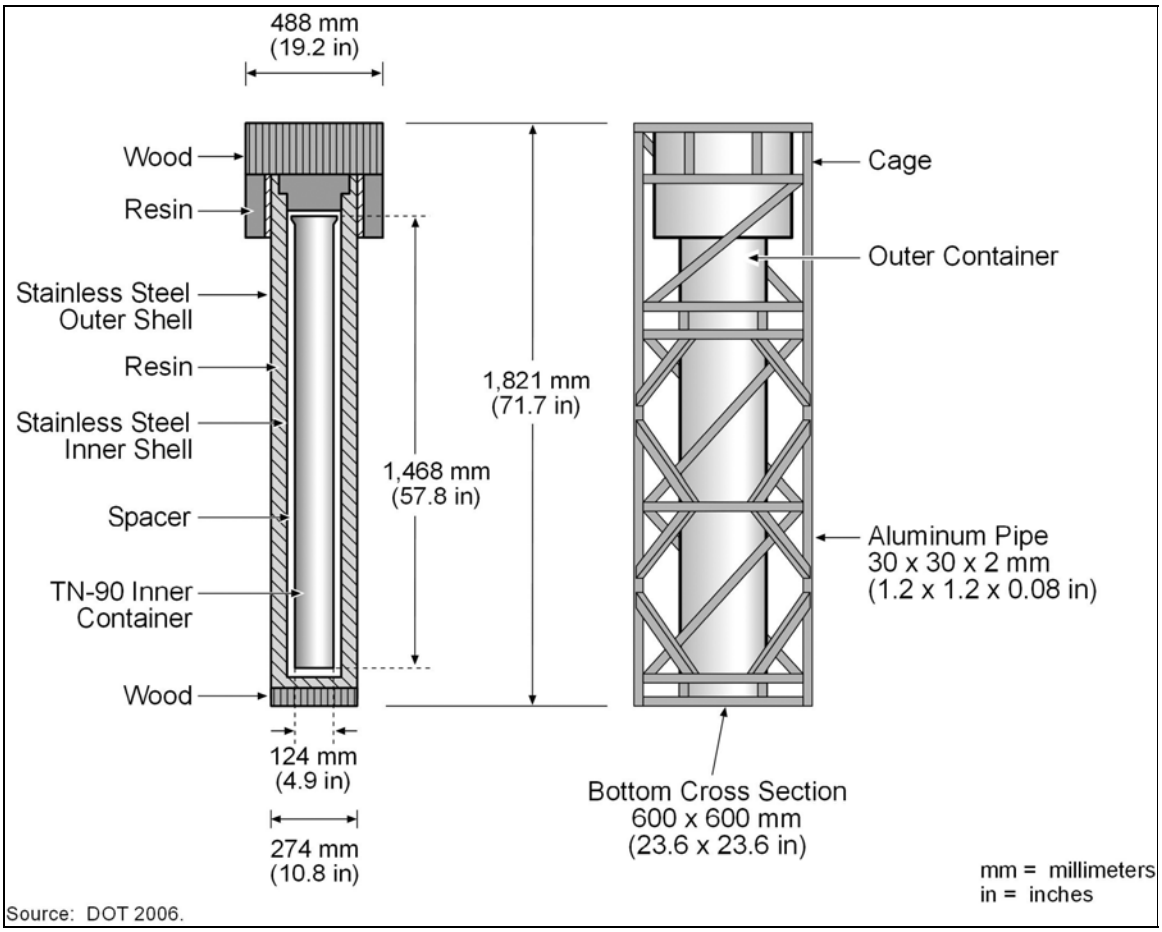

Figure 2–1 TN-BGC1 Transportation Package Includes Confinement/Containment Barriers and a Protective Cage

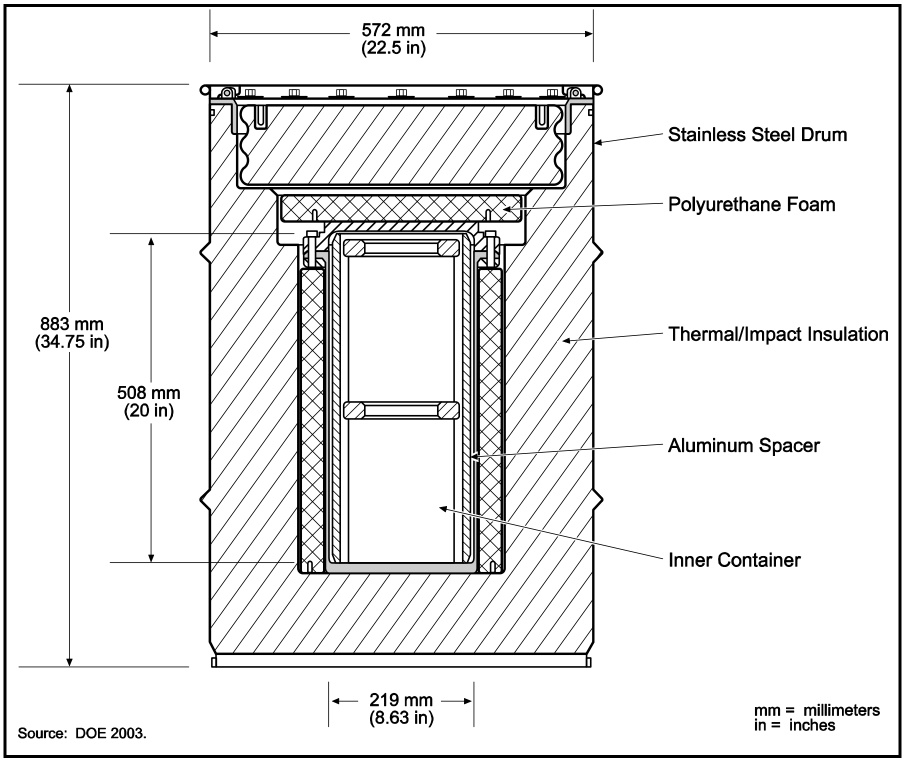

Figure 2–2 ES-2100 Transportation Package Uses a 55-Gallon Stainless Steel Drum as the Outer Confinement Layer

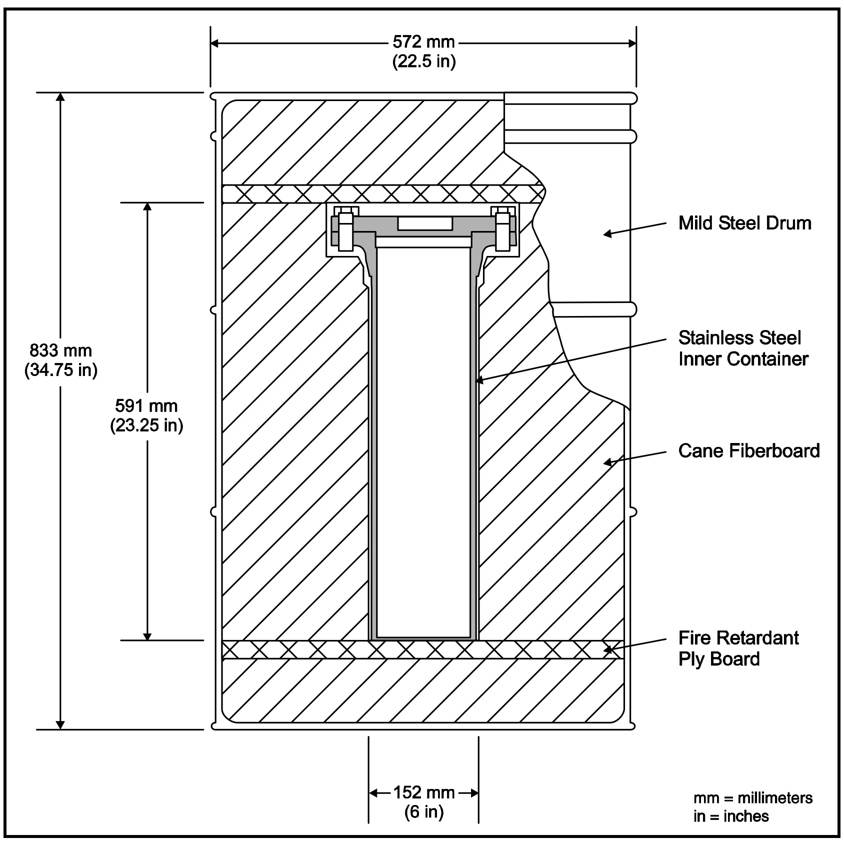

Figure 2–3 5X22 Shipping Container

2.3 Air Transport

The shipments of enriched uranium addressed in this SA would constitute a fraction of all shipments of radioactive materials in the United States and worldwide. About 44,000 air shipments of hazardous materials are made daily in the United States, involving about 4,000 tons (8 million pounds) of hazardous materials (DOT 1998). This converts to about 16 million annual shipments (1.5 million tons or 3 billion pounds) of hazardous materials in the United States by air. Hazardous materials include radioactive materials. By all modes of transport, about 250,000 annual shipments of radioactive materials are made in the United States (NEI 2005); and about 20 million annual shipments are made worldwide (WNTI 2006). Most shipments of radioactive materials are for medical and industrial applications. The United States Government Accounting Office (GAO) has estimated that over 8 percent of the total radioactive tonnage shipped in 1997 was shipped by air, of which about 75 percent was delivered by major delivery services, such as Federal Express or United Parcel Service, and 25 percent was delivered by passenger aircraft in cargo compartments (GAO 2003).

Air transport of the enriched uranium could occur using a variety of civilian or military cargo aircraft. Specifications for several example aircraft are summarized in **Table 2–3**.

Table 2–3 Specifications of Typical Civilian and Military Cargo Aircraft

Civilian Cargo Aircraft				
Parameter	***A310-200F***	***B-747-400F***	***B-767-300F***	***B-777F***
Cruising speed in kilometers per hour (miles per hour)	850 (528)	901 (566)	853 (530)	896 (557)
Cargo Compartment Dimensions	36 meters long, 3.2 meters wide	56 meters long, 3.0 meters high, 5.8 meters wide	34 meters long, 4.7 meters wide	~45 meters long, ~5.5 meters wide
Range in kilometers (miles)	5,948 (3,697)	Up to ~11,300 (7,000)	8,400 to 11,900 (5,200 to 7,400)	8,000 (4,965)
Typical Crew Size	2-4 [a]	2-4 [a]	2-4 [a]	2-4 [a]
U.S. Military Cargo Aircraft				
Parameter	***C-141*** [b]	***C-5***	***C-17***	***KC-10E*** [b]
Cruising speed in kilometers per hour (miles per hour)	805 (500)	833 (518)	833 (518)	996 (619)
Cargo Compartment Dimensions	28 meters long, 2.7 meters high, 3.1 meters wide	44 meters long, 4.1 meters, 5.8 meters wide	27 meters long, 5.5 meters wide, 3.7 meters high	38 meters long, 5.5 meters wide, 2.4 meters high
Range	Global	Global	Global	Global
Typical Crew Size	5 [c]	7 [c]	3 [c]	4 [c]

[a] Normal crew size is two. For very long distance flights, a third (relief) pilot may be aboard, as well as a cargo handler. For this SA, a total of 4 crewmembers was assumed.
[b] Use of this aircraft is less likely.
[c] Military crew size may vary depending on the need for relief crews, the need for additional cargo specialists, or the presence of personnel on training flights. For this SA, a total of 11 crewmembers was assumed.
Note: To convert meters to feet, multiply by 3.3.
Sources: Aerospace Technology 2006; Air Force 2006; Boeing 2006a, 2006b, 2006c; Campbell 2006a, 2006b; Federation of American Scientists 1999; Jane's Civil Aerospace News 2000a, 2000b; NEI 2005; NOAA 2000, NRC 1998; PANYNJ 2006a, 2006b, 2006c; SNL 2003; Tabmag 2006; UIC 2005.

Shorter distances (e.g., from locations in Europe and South America) could be traversed by civilian airplanes commonly used in commercial cargo fleets (e.g., Airbus 310), while longer distances – such as those from Asia – could be traversed by some of the larger cargo planes (e.g., Airbus 340 and

Boeing 747). Military cargo aircraft such as the C-5 Galaxy or the C-17 Globemaster are capable of mid-air refueling and, therefore, have a global range.

The mass of enriched uranium to be transported would constitute a small fraction of the payloads of typical commercial and military cargo airplanes. For example, the payload of a Boeing 747-400 is over 100,000 kilograms (220,000 pounds), while the payload of a C-17 Globemaster is 77,520 kilograms (170,900 pounds) (DOE 2004a, 2005a). The maximum weight of a loaded TN-BGC1 cask would be 396 kilograms (870 pounds). The number of packages for a 5-kilogram (11-pound) shipment may range from one to a few, depending on the physical form of the material. The number of packages for a 100-kilogram (220-pound) shipment may be up to 16, assuming that each package is limited by fissile material limits rather than physical form. The total weight of 2 packages could be up to about 800 kilograms (1,800 pounds), which would represent less than one percent of the payload of a Boeing 747-400. The total weight of 20 packages could be up to about 8,000 kilograms (about 17,600 pounds), which would represent only about ten percent of the payload of a C-17.

2.3.1 Commercial Air Shipment

Commercial air shipment is assumed for shipments of enriched uranium in quantities not exceeding DOE Category III quantities of special nuclear material (IAEA Category II quantities). Commercial shipment is considered acceptable for small shipments of HEU not contained in highly attractive forms that could be easily converted into material which can be used to manufacture weapons or an explosive device. Shipment would be carried out by a commercial organization having extensive experience in transporting nuclear materials, including both irradiated and unirradiated nuclear fuel.[13]

The enriched uranium would be transported via commercial cargo aircraft to an airport within the United States (see Section 3.2). At this airport, the packages of enriched uranium would be transferred into an exclusive-use, commercially-operated truck for transport to the Y-12 Complex.

The airport used as a port of entry for a specific trip would depend on the routes that commercial cargo carriers typically use when flying from a particular airport of departure. **Table 2–4** shows the total travel distance and flight durations of shipments between several hypothetical airports of departure around the world and possible United States airports of entry. The times presented are for non-stop shipments, including a half-hour of ground time on each end of the flight for ground operations.

Because it is not possible to specify the airports of departure or entry, bounding distances and flight times are assumed for purposes of estimating crew doses during transport. To establish a bounding flight distance and time, this SA analyzes the farthest distance that could be traveled, which is assumed to be one-half the circumference of the earth, which is 20,038 kilometers (12,451 miles).[14] In addition, because it is not possible to specify the aircraft that may be used, a composite civilian aircraft was assumed based on the information in Table 2–3 and on information from an international shipper of radioactive material (Campbell 2006a, 2006b). The characteristics of this composite aircraft are summarized in **Table 2–5**.

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[13] A summary of DOE and IAEA categories of special nuclear material is in the Foreign Reactor Fuel EA (DOE 2005a) for enriched uranium. Under the IAEA categorization system, a quantity of HEU equal to or exceeding 5 kilograms of HEU is Category I material. In this SA, IAEA Category I materials were assumed to be shipped by military rather than commercial aircraft. LEU shipped in sufficient quantity to be covered under the IAEA categorization system may be IAEA Category II or III material, but not IAEA Category I material. If the LEU uranium-235 enrichment is less than 20 percent but larger than or equal to 10 percent, the material is IAEA Category II if the quantity equals or exceeds 10 kilograms, or IAEA Category III if the quantity is less than 10 kilograms but more than 1 kilogram. If the LEU uranium-235 enrichment is above natural levels but less than 10 percent, the material is Category III if the quantity equals or exceeds 10 kilograms. Under the DOE system, HEU may be DOE Category I, II, III, or IV depending on enrichment, quantity, and attractiveness. LEU in any form or quantity is DOE Category IV material.

[14] The circumference of the earth at the equator is 40,076 kilometers (24,902 miles). From liberty.com: eclectic content (www.lyberty.com/encyc/articles/earth.html).

Table 2–4 Travel Distance and Duration for Hypothetical Non-Stop Commercial Cargo Routes

Location of Airport of Departure	*Possible Airport(s) of Entry*	*Total Distance (kilometers)*	*Duration [a] (hours:min)*
Buenos Aires, Argentina	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	8,071	10:15
	Miami International Airport, Miami, Florida	7,113	9:15
Melbourne, Australia	John F. Kennedy International Airport, New York, New York	16,684	20:35
	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	15,582	19:17
	Memphis International Airport, Memphis, Tennessee	15,158	18:47
	Los Angeles International Airport, Los Angeles, California	12,749	15:57
Paris, France	John F. Kennedy International Airport, New York, New York	5,829	7:45
	Chicago O'Hare Airport, Chicago, Illinois	6,656	8:45
	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	7,049	9:15
	Memphis International Airport, Memphis, Tennessee	7,313	9:30
Frankfurt, Germany	John F. Kennedy International Airport, New York, New York	6,183	8:15
	Chicago O'Hare Airport, Chicago, Illinois	6,962	9:00
	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	7,401	9:30
	Memphis International Airport, Memphis, Tennessee	7,641	9:45
Islamabad, Pakistan	John F. Kennedy International Airport, New York, New York	11,080	14:00
	Chicago O'Hare Airport, Chicago, Illinois	11,380	14:21
Jakarta, Indonesia	John F. Kennedy International Airport, New York, New York	16,166	19:58
	Chicago O'Hare Airport, Chicago, Illinois	15,767	19:30
	Los Angeles International Airport, Los Angeles, California	14,441	17:57
Johannesburg, South Africa	John F. Kennedy International Airport, New York, New York	12,822	16:03
	Miami International Airport, Miami, Florida	12,964	16:12
Seoul, Republic of Korea	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	11,456	14:00
	Los Angeles International Airport, Los Angeles, California	9,619	12:17
Tokyo, Japan	Hartsfield-Jackson Atlanta International Airport, Atlanta, Georgia	11,054	13:30
	Los Angeles International Airport, Los Angeles, California	8,748	11:16

[a] Duration includes an allowance of one-half hour for ground operations at each end of the flight, or a total of 1 hour for ground operations.

Note: To convert kilometers to miles, multiply by 0.62.

Source: ARI 2006.

Table 2–5 Characteristics of Composite Civilian Cargo Aircraft

Parameter	*Value*
Cruising speed in kilometers per hour (miles per hour)	853 (530)
Number of crewmembers	4
Average distance of HEU to crew during flight in meters (feet)	21 (69)
Crew exposure time for a 20,038-kilometer (12,424 miles) flight, including in-plane ground time (hours)	33

HEU = highly enriched uranium.

A crew size of four is assumed to account for the need for relief crewmembers for long distance flights. This crew size is not limiting with regard to environmental impacts. Note that it may be unlikely for the same crewmembers to complete a flight of such an extreme distance. For safety reasons involving fatigue, there are restrictions on the number of consecutive hours that an aircrew member can remain on duty, and on required rest intervals between flights. These restrictions may vary depending on national or company requirements and policies, but it can be assumed that a pilot would be replaced with another pilot after flying the authorized number of duty hours. Replaced crewmembers may or may not ride aboard the airplane for the rest of the journey.

Assuming an average flight speed of 853 kilometers per hour (530 miles per hour), a distance of 20,038 kilometers (12,424 miles) could be flown non-stop in 23.5 hours. One or two interim stops could be required, in addition to ground time at the beginnings and ends of the flights. Assuming two stops of four hours each, an allowance of one-half hour ground time at each end of the flight, and rounding to the next whole hour, a total flight time of 33 hours is assumed as a bounding case. This time is longer than any of the hypothetical flight times listed in Table 2–4.

2.3.2 Military Air Shipment

Military air transport is assumed for shipments of HEU in DOE Category I and II quantities (IAEA Category I quantities, called Formula Quantities of Special Nuclear Material in NRC regulations). Air transport would be to a military airbase. At the airbase, the HEU would be transferred to SST/SGTs for delivery to the Y-12 Complex.[15]

Flight speeds of military aircraft may be somewhat slower than their civilian counterparts; however, military cargo aircraft would be generally capable of mid-air refueling. Because the actual type of aircraft cannot be specified, a composite military aircraft was assumed to have the characteristics listed in **Table 2–6**. The composite aircraft was assumed based on Table 2–4 and other information (Campbell 2006a, 2006b).

Table 2–6 Characteristics of Composite Military Cargo Aircraft

Parameter	*Value*
Cruising speed in kilometers per hour (miles per hour)	805 (500)
Number of crewmembers	11
Average distance of HEU to crew during flight in meters (feet)	17 (56)
Crew exposure time for 20,038-kilometer (12,424 miles) flight including in-plane ground time (hours)	34

A crew size of 11 is assumed, based on the assumption of relief crewmembers, the possible presence of military personnel undergoing training, and the presence of NNSA personnel (including radiological control technicians) to monitor the shipment. This crew size is not limiting with regard to environmental impacts. Similar to commercial flight operations, military crewmembers can only fly a limited number of duty hours before replacement. Authorized duty hours can range up to 14 to 16 (Campbell 2006c). As for commercial flights, military crewmembers on very long-range flights may or may not accompany the aircraft for the entire duration of a flight of extreme length.

[15] *SST/SGT vehicles are specially designed semi-trailers pulled by armored tractors that use penetration resistance and delay mechanisms to prevent unauthorized cargo removal. SST/SGT vehicles are escorted by armed and specially-trained Federal agents equipped with communications and electronics systems, radiological monitoring equipment, and other equipment to enhance safety and security.*

Assuming an average flight speed of 805 kilometers per hour (500 miles per hour), a distance of 20,038 kilometers (12,424 miles) can be flown non-stop in 24.9 hours. Again, one or two interim stops could be required in addition to a one-half-hour ground time at the beginning and end of each flight. Assuming two stops of four hours each, an additional hour of ground time, and rounding to the next whole hour, a total flight time of 34 hours was assumed.

2.3.3 Hypothetical Airports of Entry Considered for Analyses

Air transport to all possible commercial airports and military airbases of entry in the United States is not specifically evaluated in this SA. Instead, it was assumed, based on past analyses, that impacts from incident-free transportation would be similar, if not identical, for any commercial airport or military airbase having the infrastructure necessary for long-distance cargo aircraft. However, because impacts from possible accidents at airports depend on the size and radial distribution of the surrounding populations at these airports, the SA considers as hypothetical examples the use of three major airports as likely ports of entry for commercial carriers (John F. Kennedy International Airport [JFK] International, Newark Liberty International, and Los Angeles International). Due to the large populations densities surrounding these airports, accident impacts calculated for these airports would bound those impacts that could be determined for other commercial airports. The SA also considers as a hypothetical example use of a single military airbase. Accident impacts calculated for this airbase would bound those impacts for airbases having smaller surrounding population densities.

2.4 Ocean Transport

Ocean transport of HEU (or LEU) is expected to principally occur as part of co-shipments of spent nuclear fuel to the United States. Most spent nuclear fuel shipments have been received at the Charleston Naval Weapons Station in South Carolina. The types of vessels that could be used for these shipments are described in Appendix C of the *FRR SNF EIS* (DOE 1996a). These include container vessels, roll-on/roll-off vessels, general cargo (breakbulk) vessels, and vessels specifically designed to transport spent nuclear fuel casks. Purpose-built vessels have double bottoms and hulls, watertight compartments, and collision-damage-resisting structures within the cargo and incorporate security features and satellite tracking systems. The vessel crew is trained in the handling of the cargo and in emergency response.

Approximately 300 sea voyages have been made carrying spent nuclear fuel or high-level radioactive waste over a distance of more than 8 million kilometers (5 million miles). The major company involved has transported over 400 casks, each of about 100 metric tons (100,000 kilograms or 220,000 pounds), carrying 8,000 metric tons (8 million kilograms or 17.6 million pounds) of spent fuel or waste. A quarter of these shipments have traversed the Panama Canal (UIC 2005). As of early 2004, 28 ocean shipments of spent nuclear fuel have been made to the United States as part of NNSA's foreign research reactor spent nuclear fuel acceptance program. About 3 to 4 shipments of up to 30 casks of spent nuclear fuel have annually occurred as part of this program (DOE 2004b).

At the seaport, the enriched uranium would be transferred to ground vehicles for transport to the Y-12 Complex. If the enriched uranium is co-shipped with spent nuclear fuel, it would be placed in a separate International Standards Organization (ISO) container (preferred for ocean shipping of HEU). Once unloaded from the vessel, the enriched uranium packages would be placed onto SST/SGTs for transport to the Y-12 Complex.

2.5 Shipment Safety and Security

Transport of the enriched uranium to the United States, transfer of the enriched uranium to vehicles for ground transportation to the Y-12 Complex, transportation to the Y-12 Complex, and management at the Y-12 Complex would occur in accordance with national and international safety and security requirements and procedures. These requirements and procedures are described in the *Foreign Reactor Fuel EA* (DOE 2005a).

3.0 AFFECTED ENVIRONMENT

This chapter describes the affected environment of those areas potentially impacted by the transportation of enriched uranium over the global commons by commercial or military air transport. The global commons includes the oceans of the world and the international air space that would be traversed by transport aircraft. The descriptions of affected environment presented herein and in referenced documents provide the context for understanding the environmental consequences described in Chapter 4.

3.1 Global Commons – Ocean

This section summarizes information about the global commons, specifically the ocean environment, as extracted from the *Foreign Reactor Fuel EA* (DOE 2005a). Additional information about the global commons is in the *Project Sapphire EA* (DOE 1994) and the *Russian HEU Transport EA* (DOE 2004a). A description of the potentially affected ocean environment is presented here because the analysis of impacts in Chapter 4 includes consideration of an in-flight accident over the ocean. The effect of localized radionuclide dispersal in seawater is the primary impact of concern, and the discussion below identifies the parameters included in earlier analyses.

Although the salinity of seawater is around 35 parts per thousand, it is generally lower in high latitudes and higher in low latitudes. Seawater contains the majority of the known elements. Although the total concentration of dissolved salt varies from place to place, the ratios of the more abundant components remain almost constant. This may be taken as evidence that, over geologic time, the oceans have become well mixed.

Naturally occurring radionuclides are present in seawater and marine organisms at concentrations generally greater than in terrestrial ecosystems. The ocean water concentrations of a number of isotopes are shown in **Table 3–1**. The high natural radionuclide levels make ocean ecosystems the highest background-radiation domains in the biosphere.

Table 3–1 Oceanic Concentrations of Naturally Occurring Radionuclides

Radionuclide	*Concentration (picocuries per liter)*
Carbon-14	1.8
Potassium-40	486
Rubidium-87	3
Thorium-232	540
Tritium (hydrogen-3)	3
Uranium-234	1.30
Uranium-235	0.05
Uranium-236	1.20

Note: 1 picocurie = 1.0×10^{-12} curies, 1 liter = 0.26 gallons.
Source: DOE 1996a.

Radionuclides have been discharged into the ocean since 1944. In 1981, it was estimated that the total input of radionuclides, essentially from waste disposal and nuclear weapons testing, approached 0.7 percent of the natural radioactivity present in the oceans. The total inventory of natural radioactivity in the oceans is approximately 5.0×10^{11} curies.

The relationship between environmental concentrations of radionuclides and the concentration found in organisms is important in the study of food chain effects. Bioaccumulation, the increase in concentration in organisms progressively further up the food web, is observed in marine ecosystems. In the marine environment, uranium has not been found to bioaccumulate in fish and only slightly bioaccumulates in crustaceans and mollusks.

The deep-sea bottom dwellers, or benthos, are highly diverse, with many taxonomic (classification) groups being represented by more species than most shallow-water communities. However, the number of individual organisms in a given area decreases in the deep seas and this, together with a general tendency for the average size of the organisms to also decrease, results in a dramatic reduction in standing stock or biomass on the deep ocean floor. The approximate total wet weight of bottom-living organisms decreases from 10 to 100 grams per square meter (0.2 to 2.3 pounds per square foot) on the continental shelf, to 1 to 10 grams per square meter (0.02 to 0.2 pounds per square foot) on the continental slope, and to only 0.1 to 1.0 grams per square meter (0.002 to 0.02 pounds per square foot) on the abyssal plain (deep ocean).

3.2 Commercial Airports

Many airports in the United States are large and have sufficient infrastructure to receive large cargo aircraft. The *Foreign Reactor Fuel EA* considered the shipment of HEU from four foreign countries to five large airports in the United States that could be used as ports of entry. These airports were selected because of their availability for commercial non-passenger or military flights (DOE 2005a):

- Hartsfield-Jackson Atlanta International Airport;
- JFK International Airport;
- Chicago O’Hare International Airport;
- Miami International Airport; and
- Memphis International Airport.

The affected environments for these five airports are discussed in the *Foreign Reactor Fuel EA* (DOE 2005a).

For this SA, the concern is to bound the environmental impacts that could result from HEU shipments, considering both incident-free transport and accident conditions. Based on the *Foreign Reactor Fuel EA*, there would be little or no difference in radiological impacts to ground personnel among any airport suitable for receiving long-distance cargo flights. Because the largest impacts from accidents were calculated in the *Foreign Reactor Fuel EA* for JFK International Airport, that airport alone among the five addressed in the *Foreign Reactor Fuel EA* is considered here. In addition, two other airports were considered in this SA based on the densities of the populations in their vicinities. Therefore, the three airports addressed in this SA are:

- JFK International Airport in New York City, New York;
- Newark Liberty International Airport in Newark, New Jersey; and
- Los Angeles International Airport (LAX) in the City of Los Angeles, California.

Summary descriptions of these three commercial airports are provided below.

3.2.1 John F. Kennedy International Airport

JFK International Airport is located in the southeastern section of Queens County, New York City, on Jamaica Bay due north of the Rockaway Peninsula. It is operated by the Port Authority of New York and New Jersey. It is about 24 kilometers (15 miles) from midtown Manhattan. JFK International Airport is situated on 1,995 hectares (4,930 acres), at about 3.9 meters (12.7 feet) above sea level. The airport has more than 48 kilometers (30 miles) of roadway. JFK International Airport has two pairs of parallel runways aligned at right angles with a total runway length of 14 kilometers (9 miles). All runways have high-intensity runway edge, centerline and taxiway exit lighting; and are grooved to improve skid resistance and minimize hydroplaning. In 2005, JFK International Airport handled nearly 41 million passengers, along with 1.6 million metric tons (1.7 million tons or 3.4 billion pounds) of air cargo and 75,000 metric tons (83,000 tons or 170 million pounds) of airmail. In 2004, JFK International Airport accommodated 320,013 aircraft movements (takeoffs and landings), including 9,274 movements of domestic cargo aircraft, and 14,630 movements of international cargo aircraft (PANYNJ 2006c). In 2005, JFK International Airport accommodated 349,518 plane movements of all types (PANYNJ 2006a).

In 2000, the population of Queens County was 2,229,379, with a population density of 78.8 per hectare (20,409 per square mile). The 2004 population was estimated to be 2,237,216 (Census 2006). About 35,000 people are employed at the airport (PANYNJ 2006a).

3.2.2 Newark Liberty International Airport

Newark Liberty International Airport is located in Essex and Union Counties, New Jersey, about 16 miles from midtown Manhattan. It is operated by the Port Authority of New York and New Jersey (PANYNJ 2006b). In 2004, there were 437,435 takeoffs and landings, handling nearly 32 million passengers (PANYNJ 2006c). The airport occupies 820 hectares (2,027 acres) of land at an elevation of 5.6 meters (18.3 feet) above sea level. The airport has three runways ranging in length from 2,070 meters (6,800 feet) to 3,350 meters (11,000 feet) and more than 19 kilometers (12 miles) of taxiways (PANYNJ 2006b).

The airport is served by more than four dozen national and international airlines. The airport has three main passenger terminals, including a large international passenger facility, as well as several cargo buildings, including a Federal Express cargo complex, a United Parcel Service building, a multi-tenant air cargo terminal building, and cargo handling facilities for United and Continental Airlines. Current cargo space at Newark Liberty International Airport is about 121,000 square meters (1.3 million square feet) (PANYNJ 2006b). In 2004, the airport experienced 25,058 movements of domestic cargo aircraft, and 2,069 movements of international cargo aircraft. Cargo shipments in 2004 included 670,410 metric tons (739,005 tons or 1.5 billion pounds) of domestic cargo and 232,466 metric tons (256,251 tons or 513 million pounds) of international cargo (PANYNJ 2006c).

The largest city in New Jersey is Newark, with a population estimated as 280,451 in 2004, an increase of 2.5 percent from 2000 (Wikipedia 2006a). Over 24,000 people are employed at the airport, and about 110,000 jobs are derived from airport activities (PANYNJ 2006b).

3.2.3 Los Angeles International Airport

Los Angeles International Airport (LAX) is located in the City of Los Angeles, in the County of Los Angeles, California, adjacent to the Pacific Ocean. In 2003, there were 622,378 takeoffs and landings, and the airport handled 14.6 million international and 40.3 million domestic passengers. The airport occupies 1,386 hectares (3,425 acres) of land at an elevation of 38.3 meters (125.55 feet). The airport has four east-west parallel runways, ranging in length from 2,719 meters (8,925 feet) to 3,680 meters (12,090 feet) (LAWA 2006a).

The airport is served by 80 passenger carriers and 20 cargo carriers. There are nine terminals. The cargo terminals have over two million square feet of cargo handling area. In 2003, LAX ranked sixth worldwide in tons of air cargo handled, with more than 1.8 million metric tons (2 million tons or 4 billion pounds) of freight and mail shipped (LAWA 2006a). International freight comprised more than 50 percent of this total (LAWA 2006b).

As of the 2000 Census, the City of Los Angeles had a population of 3.69 million, although the population in a July 1, 2004 estimate was 3.85 million. Ten million persons reside in Los Angeles County. The city covers more than 1,200 square kilometers (465 square miles) (Wikipedia 2006b). An estimated 59,000 jobs directly attributable to LAX are located on or near the airport, while 408,000 jobs in the surrounding region are attributable to LAX (LAWA 2006b).

3.3 Military Airbase

A specific military airbase is not identified. A military airbase would be selected such that its runway would be adequate for the aircraft used for transport. The military airbase used for this SA has the population characteristics of a major metropolitan area.

3.4 Seaport

More than one seaport may be used to receive ocean shipments of HEU. Two representative mid-Atlantic Coast military ports include the Norfolk Naval Station in Virginia or the Charleston Naval Weapons Station in South Carolina. The affected environments for these seaports are described in Appendix D of the *FRR SNF EIS* (DOE 1996a). From experience with past shipments of foreign research reactor spent nuclear fuel to the United States, the most likely seaport would be Charleston (DOE 2004b).

4.0 ENVIRONMENTAL IMPACTS

This chapter describes the environmental impacts from incident-free operations and accident conditions during transport of HEU from foreign nations to the United States. Potential radiological impacts associated with shipment of the HEU for both incident-free operations and accident conditions would be small regardless of the transportation packages used. Potential nonradiological impacts of unirradiated HEU transport on the global commons would be minor for both normal and accident conditions.[16]

4.1 Summary of Impacts

Impacts from Air Transport. Potential radiological impacts associated with HEU air transport through the global commons (assuming an external package dose rate of 1 millirem per hour at 1 meter (3.3 feet) from the package surface) are summarized below:

- An aircrew member could receive a dose of up to 0.28 millirem from a single 5-kilogram (11-pound) shipment of HEU by commercial cargo aircraft, corresponding to a risk of 1.7×10^{-7} (LCF), or about 1 chance in 6 million.[17] An aircrew member could receive a dose of up to 0.51 millirem from a single 100-kilogram (220-pound) shipment of HEU by military cargo aircraft, corresponding to a risk of 3.1×10^{-7} LCF (1 chance in 3.2 million). The dose to this crewmember from a single 50-kilogram (110-pound) shipment of HEU would be similar.

- Risks to all aircrew members[18] from shipment of 100 kilograms (220 pounds) of HEU are as follows: For 20 flights to commercial airports at 5 kilograms (11 pounds) per flight, the total aircrew dose is 0.022 person-rem (1.3×10^{-5} LCF, about 1 chance in 75,000). For one flight to a military airbase at 100 kilograms (220 pounds) per flight, the total aircrew dose is 0.0056 person-rem (3.4×10^{-6} LCF, about 1 chance in 300,000). For two flights to a military airbase at 50 kilograms (110 pounds) per flight, the total aircrew dose is 0.011 person-rem (6.6×10^{-6} LCF, about 1 chance in 152,000).

- The total dose and risk for all aircrew members[18] for all shipments of HEU over a period of 10 years could be up to 1.1 person-rem (6.7×10^{-4} LCF, or about 1 chance in 1,500) if all shipments were 5-kilogram (11-pound) commercial shipments, up to 0.28 person rem (1.7×10^{-4} LCF, about 1 chance in 5,900) if all shipments were 100-kilogram (220-pound) military shipments, or up to 0.56 person-rem (3.4×10^{-4} LCF, about 1 chance in 2,900) if all shipments were 50-kilogram (110-pound) military shipments.

- Assuming the occurrence of a severe aircraft landing-stall-fire accident at a commercial airport, a maximally exposed individual (MEI) member of the public or a worker not directly involved with the shipment at the airfield would have an increased risk of up to 4.2×10^{-8} LCF (about 1 chance in 24 million) and 6.8×10^{-6} LCF (about 1 chance in a 147,000), respectively.[19] Taking into account the probability that such a severe accident could occur, the corresponding LCF risks are 1.18×10^{-14} (about 1 chance in 85 trillion) and 1.9×10^{-12} (about 1 chance in 526 billion),

[16] *The environmental impacts analyzed in this section would be the same if the enriched uranium was shipped to the United States from foreign countries, or if the enriched uranium was shipped from the United States to foreign countries.*
[17] *Latent cancer fatalities (LCFs) were estimated assuming a risk factor of 0.0006 LCF per rem for all members of aircrew, all cargo handlers, and all members of the public.*
[18] *This analysis is based on an assumption of 4 crewmembers for all commercial flights and 11 crewmembers for all military flights.*
[19] *The MEI is located 1.6 kilometers (1 mile) from the accident site, while the noninvolved worker is located 100 meters (328 feet) from the accident site.*

respectively. Assuming a similar severe accident at a military airbase, the MEI and worker not directly involved with the shipment would have an increased risk of 4.2×10^{-7} LCF and 6.8×10^{-5} LCF (about 1 chance in 2.4 million and 1 chance in 15,000). Taking into account the probability that such a severe accident could occur, the corresponding LCF risks are 6.8×10^{-13} and 1.1×10^{-10} (about 1 chance in 2 trillion and 1 chance in 9 billion).

- The population within 80 kilometers (50 miles) of a commercial airport would likely experience no increase in LCFs from exposure to radiation from an aircraft landing-stall-fire accident, based on the calculated radiological risk (5.4×10^{-3}) being much smaller than one. Taking into account the probability that such a severe accident could occur, the corresponding LCF risk is 1.5×10^{-9} (about 1 chance in 667 million). Assuming this same accident at a military airbase, the population within 80 kilometers (50 miles) would experience a radiological LCF risk of 2.3×10^{-2} (about 1 chance in 43). Taking into account the probability that such an accident could occur, the corresponding LCF risk is 3.7×10^{-8} (about 1 chance in 27 million).

The radiation dose that any individual crewmember could receive in any single year from hypothetical multiple shipments of HEU would be limited by practical limitations of the number of flight-hours that an individual could annually sustain. Using existing practices for shipping radioactive material and historical levels of package surface radiation for shipment of HEU, no crewmember would receive a dose from the HEU in excess of DOE's and NRC's radiation dose limit of 100 millirem in a year for members of the public. Radiation doses and risks from transporting the HEU would be far smaller than those from natural cosmic radiation. Radiation doses from all sources (radioactive material and cosmic radiation) would be administratively controlled to levels smaller than established occupational dose limits.

Ground Cargo Handling Impacts. Potential radiological impacts from transfer of packages from the aircraft to ground transport vehicles are summarized below:

- A worker transferring packages from the aircraft to transport vehicles would receive a radiation dose of about 0.23 millirem (increased risk of 1.4×10^{-7}, or about 1 chance in 7.3 million), assuming a single 5-kilogram (11-pound) shipment of HEU to a commercial airport. A similar worker at a military airbase would receive a radiation dose of 2.8 millirem (increased risk of 1.7×10^{-6}, about 1 chance in 595,000), assuming a single 100-kilogram (220-pound) shipment of HEU to a military base. The dose and risk to this same worker from a single 50-kilogram (110-pound) shipment to a military airbase would be roughly half that for a 100-kilogram (220-pound) shipment.

- If the same crew was hypothetically involved in as many as 10 shipments in a year at a commercial airport, the maximum individual dose to a worker would be 2.3 millirem (1.4×10^{-6} LCF, about 1 chance in 724,000) for shipping 50 kilograms (110 pounds) of HEU. If the same crew was hypothetically involved with 10 shipments to a military airbase, the doses would range from 13 to 28 millirem for ten 50-kilogram (110-pound) shipments or ten 100-kilogram (220-pound) shipments, respectively. Corresponding risks would range from 7.8×10^{-6} to 1.7×10^{-5} LCF (about 1 chance in 128,000 and 1 chance in 58,000, respectively) for ten 50-kilogram (110-pound) shipments or ten 100-kilogram (220-pound) shipments.

- A noninvolved worker monitoring the transfer would have an increased risk of an LCF of 1.0×10^{-8} (about 1 chance in 100 million) for a single 5-kilogram (11-pound) shipment to a commercial airbase. A noninvolved worker would have an increased risk of 1.2×10^{-7} LCF (about 1 chance in 8.3 million) for a single 100-kilogram (220-pound) shipment to a military airbase, or 5.8×10^{-8} LCF (about 1 chance in 17 million) for a single 50-kilogram (110-pound) shipment. If the same non-involved worker was involved with as many as ten shipments in a year, the corresponding risks would be 1.0×10^{-7} (about 1 chance in 10 million) for shipment to a commercial airport, 1.2×10^{-6} LCF (about 1 chance in 830,000) for ten 100-kilogram (220-pound) shipments to a military airbase, or 5.8×10^{-7} LCF (about 1 chance in 1.7 million) for ten 50-kilogram (110-pound) shipments to a military airbase.

- Risks to all members of the cargo handling crew[20] from receipt of 100 kilograms (220 pounds) of HEU are as follows: For 20 shipments to commercial airports at 5 kilograms (11 pounds) per shipment, the total ground crew dose is 0.01 person-rem (6.0×10^{-6} LCF, about 1 chance in 160,000). For one shipment to a military airbase at 100 kilograms (220 pounds) per shipment, the total ground crew dose is 0.0062 person-rem (3.7×10^{-6} LCF, about 1 chance in 269,000). For two shipments to a military airbase at 50 kilograms (110 pounds) per shipment, the total ground crew dose is 0.0058 person-rem (3.5×10^{-6} LCF, about 1 chance in 280,000).

Because historical experience with shipments of HEU indicate that actual package external radiation levels are at least five times smaller than those assumed for this SA, it is unlikely that the total radiation dose experienced by any individual member of a ground-loading crew over 10 years would exceed 100 millirem.

Impacts from Ocean Vessel Transport. Environmental impacts associated with ocean transport of HEU would be bounded by those in other analyses (DOE 1996a, 2004a). Impacts from shipping 166 kilograms (365 pounds) of HEU via a 21-day voyage are summarized below:

- An individual member of a vessel crew would receive a radiation dose of about 1 to 2 millirem per voyage. A dose of 2 millirem results in a risk of 1.2×10^{-6} LCF, which is about 1 chance in 830,000.

- The dose to the most highly exposed member of a dock crew unloading HEU packages was estimated to be about 8 millirem (risk of 4.8×10^{-6}, about 1 chance in 210,000); while the dose to a guard or other noninvolved worker was estimated to be 0.4 millirem (risk of 2.4×10^{-7} LCF, about 1 chance in 4.2 million).

- Assuming the occurrence of a severe accident at a dock or shipping channel involving a collision and fire causing the release of radioactive materials, the risks to an MEI and noninvolved worker, assuming the accident occurred, were 1.5×10^{-5} LCF and 2.0×10^{-5} LCF, respectively (about 1 chance in 67,000 and 1 chance in 50,000). The risks to the MEI and noninvolved worker, considering the probability of the accident occurring, were 7.4×10^{-14} LCF and 1.0×10^{-13} LCF, respectively (about 1 chance in 14 trillion and 1 chance in 10 trillion). The risk to the surrounding population was 0.025 LCF (about 1 chance in 40) assuming the occurrence of the accident, or 1.2×10^{-10} LCF (about 1 chance in 8.3 billion) considering the probability of the accident occurring.

If all HEU was shipped by ocean vessel, at 166 kilograms (365 pounds) of HEU per shipment, the total dose to either a member of a ship crew or a dock worker would be smaller than 100 millirem, assuming historical HEU package radiation dose rates. Even if all shipments were to occur during a single year, each member of a ship crew or dock worker would not receive a radiation dose exceeding DOE's and NRC's annual limit for members of the public.

Impacts from Other Air Shipment Scenarios. A wide range of international shipments of unirradiated uranium may occur over the next 10 years, and these shipments may differ from those assumed for the

[20] This assessment is based on an assumption of two loaders receiving maximum radiation exposure levels, and three guards or noninvolved workers receiving smaller levels of radiation exposure.

analysis in this SA. HEU shipments may be larger than those assumed for the SA; the surface dose rates of HEU containers may be larger than those historically experienced; different aircraft could be used (or operational procedures may change) that would reduce the average distances assumed between air and ground crew and packages of HEU; or small quantities of LEU or other radioactive materials may accompany the HEU. Therefore, Appendix A of this SA provides a method to estimate the radiological impacts from actual air shipments for both incident-free and accident conditions.

Note that although impacts from accident conditions depend on the kinds and quantities of shipped radionuclides, impacts from incident-free transport do not. For incident-free transport, radiological doses and risks to aircrew, cargo handlers, or other individuals depend on the external radiation levels at package surfaces rather than the particular mix of radionuclides inside the package that cause the external radiation. Therefore, shipping LEU or other radioactive materials with the HEU (e.g., natural or depleted uranium) would not result in environmental impacts from incident-free transport that are inconsistent with those addressed in this SA, provided that the other shipment parameters (e.g., package surface radiation levels) are compatible with the assumptions for this SA. For accidents, provided that the radioactive material shipped with the HEU is only unirradiated uranium (of any enrichment), Appendix A can be used to compare the postulated impacts from an actual air shipment of uranium with those calculated for this SA.

4.2 Impacts of Air Transport

In this SA, reference is made to three EAs that addressed air transport of HEU from foreign countries to the United States. All these assessments concluded that the Proposed Actions and their alternatives would all result in minor impacts and low levels of risk. These previous assessments are the *Project Sapphire EA* (DOE 1994), the *Russian HEU Transport EA* (DOE 2004a), and the *Foreign Reactor Fuel EA* (DOE 2005a).

The *Project Sapphire EA* (DOE 1994) addressed air transport of HEU to representative airbases. The total shipment consisted of 566 kilograms (1,250 pounds) of HEU consisting of about 26 kilograms (58 pounds) in a powdered oxide form, 187 kilograms (412 pounds) as uranium metal, 167 kilograms (368 pounds) in a uranium alloy, and 186 kilograms (410 pounds) as machine turnings and powder. The shipment was expected to be contained within two military cargo aircraft delivering the HEU in 456 6M-2R Type B containers.

The *Russian HEU Transport EA* (DOE 2004a) addressed air transport of HEU to representative airbases. The assessment considered shipment of an average of 166 kilograms (365 pounds) per year, and a maximum of 332 kilograms (732 pounds) per year. The chemical forms were uranium oxide (U_3O_8) powder and uranium metal. Shipment of 332 kilograms (732 pounds) of HEU was expected to require 48 TN-BGC1 shipping containers, 24 ES-2100 shipping containers, or 37 5X22 shipping containers (all containers are Type B).

The *Foreign Reactor Fuel EA* (DOE 2005a) addressed air transport of research reactor fuel to five representative commercial airports and a military airbase. The quantity of material shipped ranged from a total of 1.9 kilograms (4.2 pounds) of HEU from the Republic of Korea to 15.2 kilograms (33.5 pounds) of HEU from Belgium. Most of the fuel was aluminum-clad, uranium-alloy fuel, while some was stainless steel-clad, uranium-zirconium hydride fuel. The number of shipment containers was estimated to range from 4 to 29.

Table 4–1 compares the quantities of the HEU addressed in these three references with estimates of the quantities in the enriched uranium considered in this SA. Also shown is the estimated number of typical Type B containers for each shipment.

Table 4–1 Comparison of the Characteristics of the Nuclear Material Considered in this Supplement Analysis with that Considered in Comparable Environmental Assessments

Material Information	*Foreign Shipments for This SA*		*Shipment from Kazakhstan* [a]	*Annual Shipments from Russian Federation* [b]	*Shipments from Four Foreign Countries* [c]			
	Shipments of Up to 5 Kilograms (11 pounds) of HEU by Commercial Cargo Aircraft	*Shipments of Up to 100 Kilograms (220 pounds) of HEU by Military Cargo Aircraft*			*Argentina*	*Belgium*	*Japan*	*Republic of Korea*
Material form	Solid	Solid	Oxide powder; U metal; U-Be alloy; and U-Be machined turnings and powder	Oxide	U-Al alloy core clad in Al	U-Al alloy core clad in Al	U-Al alloy core clad in Al	U-ZrH core clad in stainless steel
Total HEU	Up to 5 kilograms (11 pounds)	Up to 100 kilograms (220 pounds)	566 kilograms (1,248 pounds)	166 kilograms (365 pounds)	3.8 kilograms (8.4 pounds)	15.2 kilograms (33.4 pounds)	3.4 kilograms (7.5 pounds)	1.9 kilograms (4.2 pounds)
U-235 enrichment (weight percent)	93.5 [g]	93.5 [g]	90 [d]	93 [e]	89.9	90	93.2	70
Estimated number of typical shipping containers [f]	(1) TN-BGC1, or (1) ES-2100	(16) TN-BGC1, or (8) ES-2100	456 6M-2R	(48) TN-BGC1, (24) ES-2100, or (37) 5X22	(7-10) TN-BGC1	(29) TN-BGC1	(4) TN-BGC1	(5) TN-BGC1 or (5) 5X22
Status of shipment			Completed	Ongoing	Completed	Completed	To be planned	To be planned

Al = aluminum, Be = beryllium, HEU = highly enriched uranium, U = uranium, ZrH = zirconium-hydride.

[a] DOE 1994.

[b] DOE 2004a.

[c] DOE 2005a.

[d] The estimated weight percentage of other uranium isotopes was 1 percent uranium-234 and 9 percent uranium-238.

[e] The estimated weight percentage of other uranium isotopes was 1.2 percent uranium-234, 0.46 percent uranium-236, and 5.34 percent uranium-238.

[f] Numbers and types of shipping containers are typical rather than prescriptive. Any shipping containers actually used would meet all applicable international and United States shipping requirements.

[g] The estimated weight percentage of other uranium isotopes was 0.76 percent uranium-234, 0.47 percent uranium-236, and 5.3 percent uranium-238.

For the *Project Sapphire* and *Russian HEU Transport EAs* (DOE 1994, 2004a), the quantity of HEU contained in any single shipment was larger than the quantities of HEU considered in this SA for any single commercial shipment of enriched uranium, and larger than the quantities considered in this SA for any single military shipment of enriched uranium. The quantities of HEU considered in this SA for any single commercial shipment of HEU are comparable to those considered in the *Foreign Reactor Fuel EA* (DOE 2005a). The HEU considered in the *Project Sapphire* and *Russian Transport HEU EAs* (DOE 1994, 2004a) was partly in a powder form, while the unirradiated fuel considered in the *Foreign Reactor Fuel EA* was in a less dispersible alloy form clad in aluminum or stainless steel. For this SA, the enriched uranium can potentially be in any solid form but would probably be in the form of reactor fuel similar to that analyzed in the *Foreign Reactor Fuel EA* (DOE 2005a). For purposes of a bounding analysis in this SA, the form of the enriched uranium was assumed to be a dispersible uranium oxide powder.

4.2.1 Impacts on the Global Commons

Because air transport of enriched uranium would occur over the global commons, this SA examines the potential impacts on the global commons in accordance with Executive Order 12114. Potential impacts to the global commons could result from normal operations or accident conditions.

4.2.1.1 Commercial Shipments

Normal operations would not have a significant impact on the air of the global commons. If all shipments of enriched uranium were by commercial aircraft and each shipment contained 5 kilograms (11 pounds) of HEU, then there would be 1,000 shipments of HEU over 10 years, or an average of 100 per year. Air emissions from even several hundred HEU-carrying flights per year would represent a very small percentage of the flights annually crossing the world oceans. The consequent emissions from such flights would represent a similar small percentage and would have no appreciable impact on air quality of the global commons. There are no other potential impacts to the global commons from normal operations.

As indicated in the *Project Sapphire* and *Russian HEU Transport EAs*, the response to and impacts of an in-flight accident involving the global commons (ocean) would be different depending on the location and the condition of the packages following the accident (DOE 1994, 2004a). Packages that did not sink below 200 meters (670 feet) could be located and recovered. Undamaged packages that sank deeper than 200 meters (670 feet) would be breached by the pressure of the overlying water or by corrosion, and would gradually release their contents. It was conservatively assumed that the contents of damaged packages would be immediately released into the ocean.

It was concluded that in the event of an accident, there could be some loss of life to marine organisms directly exposed to the enriched uranium. Yet because of the large volumes of water, the mixing mechanisms within it, the existing background uranium concentrations, and the radiation-resistance of aquatic organisms, the radiological impacts of an accident would be localized and of minor impact. Only very localized and minor impacts on the global commons were postulated for an air transport accident (DOE 1994, 2004a).

The quantity of HEU shipped that would be contained in any single shipment of enriched uranium via commercial aircraft is much smaller than the quantities addressed in the *Project Sapphire* and *Russian HEU Transport EAs*. Most shipments addressed in this SA would typically be fuel elements of uranium clad in aluminum or stainless steel, but some may be in powdered form. Therefore, the impacts from an accident involving the global commons from transporting enriched uranium from the foreign nations to the United States would be smaller than those assessed in those two references (DOE 1994, 2004a).

4.2.1.2 Military Shipments

Shipments from foreign countries via military air transport to a military airbase would, again, mostly involve transport over the global commons. Although different types of aircraft would be used than those commonly used for commercial transport, nonradiological impacts such as air emissions would be similar for individual shipments. That is, military aircraft containing 100 kilograms (220 pounds) of HEU would have similar nonradiological impacts as commercial aircraft carrying 5 kilograms (11 pounds) of HEU. However, the total number of military shipments, and, therefore, the total quantity of nonradiological pollutants that could be emitted to the environment, would be smaller than that for the commercial shipments. Assuming 100-kilogram (220-pound) military shipments, only 50 air shipments would be required to transport 5,000 kilograms (11,000 pounds) of enriched uranium over 10 years, or an average of 5 per year. (Some military flights could require flights of air-to-air refueling aircraft.) In practice, however, some shipments may be by commercial cargo aircraft and others by military aircraft. In addition, the quantity of HEU carried in any shipment may vary from the quantities assumed for this SA. Therefore, the total number of air shipments could range from 50 to 1,000 over 10 years (see Table 4–5).

Regarding possible aircraft accidents involving the global commons, the total quantity of material analyzed in this SA in any single military shipment is smaller than that considered in previous assessments (the *Project Sapphire* and *Russian HEU Transport EAs*). Again, most shipments addressed in this SA would probably be comprised of uranium clad in metal, but some may be in powdered form. Therefore, the conclusions reached above regarding the environmental impacts of commercial aircraft accidents would also apply to military shipments. The impacts from an accident involving the global commons from transporting enriched uranium to the United States would be smaller than those assessed in those two references (DOE 1994, 2004a).

4.2.2 Impacts from Incident-Free Air Transportation

Incident-free transport of HEU via commercial or military cargo aircraft would result in radiological exposure only to the personnel on the aircraft. Because of the relatively large distance to the nearest members of the public, there would be no radiological exposure to the public. The radiological dose received by persons on the cargo plane (crew) would be proportional to the package surface dose rate, the crew-view package characteristic dimensions (i.e., the surface of the package array that faces the crew), the crew-to-package distance, and the time between boarding in the aircraft (at a foreign international airport) and exiting at a final destination (at an airport in the United States).

The dose rate was assumed to be one millirem per hour, at one meter (3.3 feet) from the package. This dose rate was selected to be conservative and consistent with the Y-12 Complex package dose rate acceptance criteria of less than two millirem per hour at 0.30 meters (1 foot) from the package. The actual dose rate for HEU packages is expected to be smaller than one millirem per hour, consistent with DOE’s experience in transport of HEU. Current experience indicates an external dose rate of less than 0.2 millirem per hour at 0.30 meters (1 foot) from package. The crew-view package characteristic dimension is a function of the package configuration, which, in turn, is dependent on the size and number of packages and space limitations in the cargo plane.

Table 4–2 presents specific recent experience in DOE package measured dose rates from transportation of enriched uranium similar to that considered in this SA.

Table 4–2 Recent Enriched Uranium Transportation Package Measured Gamma Dose Rates

Year	*Transportation Package Model*	*Uranium Mass (kilogram)*	*Uranium-235 Enrichment*	*Physical Form*	*Average Gamma Dose Rate at 1 Foot (0.3 meters) from Surface (millirem per hour)*
2005	6M-110	7.7	6 percent	UO_2 pellets	0.2
2005	6M-55	1	90 percent	U-Al	0.2
2006	5X22	0.4	93 percent	U-Al billets	0.11
2006	5X22	3.05	83 percent	U_3O_8	0.17
2006	TN-BGC1	0.52	90 percent	U-Al plates	0.12
2006	TN-BGC1	3.7	90 percent	U-Al plates	0.26

UO_2 = uranium dioxide, U-Al = uranium aluminum alloy, U_3O_8 = uranium oxide.
Note: To convert kilograms to pounds, multiply by 2.2.
Sources: DOE 2006c, 2006d.

The HEU could be transported in a variety of transportation packages; three representative packages are addressed in this SA. Analyzing impacts using the TN-BGC1 and the ES-2100 packages provides representative results that would also be valid if the 5X22 package were used. As stated earlier, it was assumed that the amount of HEU in a military and commercial cargo aircraft would be limited to 100 and 5 kilograms (220 and 11 pounds), respectively. This is equivalent to one package (ES-2100 or TN-BGC1) per commercial cargo, and about 8 (ES-2100) or 16 (TN-BGC1) packages per military cargo, assuming that the number of packages is limited by package fissile material limits and not by the physical characteristics of the shipped material. Use of 5X22 packages would lead to about 12 packages per military cargo. Therefore, assumed use of TN-BGC1 and ES-2100 packages would be sufficient to provide a range for the potential risks that could result from transportation activities.

Based on the dimensions of typical cargo compartments and routine practices for positioning sensitive fissile material for transport,[21] the minimum distance between the HEU package and the cabin crew was determined to be 17 and 21 meters (56 and 69 feet) for the military and the commercial cargo aircraft, respectively. These packages may be transported along with other non-radioactive material packages in the cargo compartment, which would provide the crew with protection (shielding) against external radiation exposure. However, for purposes of analysis, no credit was taken for such shielding. Neither was any credit taken for any additional measures that may be taken by the flight crews to avoid radiation exposure. Incident-free impacts to the aircrew members (and to cargo handlers in Section 4.2.3) were estimated using the RADTRAN 5 computer code (SNL 2003). This standard version of RADTRAN 5 has been used extensively in numerous NEPA analyses and was not modified for calculations in support of this SA.

The results presented below are based on the aforementioned dose rate, distance, and number of crewmember assumptions. Since the data for actual shipments by commercial or military air cargo may differ from those assumed, a simple analytical method is provided in Appendix A for estimating the impact.

4.2.2.1 Commercial Air Cargo Transport

Table 4–3 provides estimates of hourly dose and risk to a single member of the crew to transport either package (TN-BGC1 or ES-2100), as well as total hourly doses to an assumed 4-member crew. The

[21] *Standard operating practice is to load the uranium containers last, which means that they would be at the rear of the aircraft well away from the flight crew, and would also be the first containers to be unloaded after landing (Campbell 2006a).*

slightly higher dose from transporting the TN-BGC1 package is due to the packaging configuration, which results in a larger crew-view package characteristic dimension (higher radiation density).

Table 4–3 Human Health Impacts from Incident-Free Air Cargo per Transport Hour

Package and Transport Mode	*Number of Packages*	*HEU Payload (kilograms)*	*Individual Crew Dose and Risk* [a]		*Total Crew Dose and Risk* [a,b]	
			Dose (rem per hour)	*Risk*	*Dose (person-rem per hour)*	*Risk*
TN-BGC1						
Military	16	100	1.51×10^{-5}	9.06×10^{-9}	1.66×10^{-4}	9.97×10^{-8}
Commercial Cargo	1	5	8.45×10^{-6}	5.07×10^{-9}	3.38×10^{-5}	2.03×10^{-8}
ES-2100						
Military	8	100	1.07×10^{-5}	6.42×10^{-9}	1.18×10^{-4}	7.06×10^{-8}
Commercial Cargo	1	5	5.25×10^{-6}	3.15×10^{-9}	2.10×10^{-5}	1.26×10^{-8}

HEU = highly enriched uranium.
[a] Risks are in terms of LCFs which were determined using a risk factor of 0.0006 per rem.
[b] The total crewmember dose was determined assuming a military flight crew of 11 and a commercial flight crew of 4.
Note: To convert kilograms to pounds, multiply by 2.2.

4.2.2.2 Military Air Cargo Transport

Each military cargo would have up to 100 kilograms (220 pounds) of HEU in TN-BGC1 or ES-2100 packages. If the TN-BGC1 package were used, the expected aircraft loading configuration would be 2 packages wide by 8 rows long. If ES-2100 transportation packages were used, the expected aircraft loading configuration would be 2 packages wide by 4 rows long. Table 4–3 provides the estimated dose and risk to a single member of the crew per transport hour for transporting either of the packages. Also shown is the total hourly dose and risk to an assumed 11-member crew.

For a single shipment of 50 kilograms (110 pounds) of HEU by military cargo aircraft, the dose and risk to crewmembers would be about the same as those from a single shipment of 100 kilograms (220 pounds) of HEU because the crew is exposed to the same package surface dose rate and distance. The number of packages would be about half those listed in Table 4–3.

4.2.2.3 Impacts for Individual Flights and for Multiple Shipments

Individual Flights

Incident-free impacts from air shipment of enriched uranium were determined by the product of the hourly dose and risk rates listed in Table 4–3 and the total flight hours required for the shipments. Although many flights would probably require less than 12 hours to complete, this SA, in **Table 4–4**, identifies the crew doses and risks for a single military or commercial flight of extreme distance (literally half-way around the world) assuming the total flight hours listed in Tables 2–5 and 2–6. During the time on the ground, the crew was conservatively assumed to remain in the aircraft, and thus receive a similar radiation dose rate as that during flight from the HEU shipment. In addition, the same crew was conservatively assumed to accompany the HEU the entire duration of its shipment.

Table 4–4 Crew Doses and Risks for a Single Military or Commercial Flight Covering an Extreme Distance

Mode	Package	*Individual Crewmember Dose and Risk*		*Total Crew Dose and Risk*		*Individual Cosmic Radiation Dose and Risk*	
		Dose (rem)	***Risk (LCF)*** [a]	***Dose (person-rem)***	***Risk (LCF)*** [a]	***Dose (rem)***	***Risk (LCF)*** [a]
Military	TN-BGC1	5.13×10^{-4}	3.08×10^{-7}	5.65×10^{-3}	3.39×10^{-6}	1.50×10^{-2}	9.00×10^{-6}
	ES-2100	3.64×10^{-4}	2.18×10^{-7}	4.00×10^{-3}	2.40×10^{-6}	1.50×10^{-2}	9.00×10^{-6}
Commercial	TN-BGC1	2.79×10^{-4}	1.67×10^{-7}	1.12×10^{-3}	6.69×10^{-7}	1.44×10^{-2}	8.64×10^{-6}
	ES-2100	1.73×10^{-4}	1.04×10^{-7}	6.93×10^{-4}	4.16×10^{-7}	1.44×10^{-2}	8.64×10^{-6}

LCF = latent cancer fatality.

[a] LCFs were determined assuming a risk of 0.0006 LCF per rem.

Note: Doses and risks from HEU shipments were determined based on a total flight time of 34 hours for a military flight and 33 hours for a commercial flight. Doses from cosmic radiation were determined based on an airborne time of 25 hours for a military flight and 24 hours for a commercial flight. For the 9 hours assumed to be spent on the ground during either commercial or military flights, aircrew were conservatively assumed to not leave the aircraft. Crew sizes were assumed to be 11 for military aircraft and 4 for commercial aircraft.

For comparison, Table 4–4 includes an estimate of the radiation dose and risk received by an individual member of the crew from cosmic radiation.[22] The dose and risk were determined only for the time in the air (that is, ground time was subtracted from the total flight duration), based on an assumed dose rate of 0.6 millirem per hour, which is the approximate hourly dose from cosmic radiation at an altitude of 35,000 feet (FAA 1990). The actual dose rate varies by altitude, latitude, and other factors. For example, information issued by the National Oceanic and Atmospheric Administration (NOAA) estimates an hourly dose rate, depending on latitude and solar minimum and maximum periods of from 0.285 to 0.406 millirem per hour at an elevation of 30,000 feet, and from 0.588 to 0.902 millirem per hour at an elevation of 40,000 feet (NOAA 2000).

Doses and risks would vary depending on the package used. For a single military flight, for example, the dose to an individual member of the crew could vary from 0.36 to 0.51 millirem, depending on whether the package was a TN-BGC1 or an ES-2100. The dose for a shipment using a 5X22 package would be similar to that for the ES-2100. Similar observations could be made about individual risk and collective dose and risk. Note that the radiation dose that the crew would receive from a shipment of HEU by either commercial or military aircraft would be far smaller than the dose that the crew would receive from cosmic radiation. This observation is consistent with that made by the Federal Aviation Agency (FAA) in Advisory Circular No. 120-52 (FAA 1990). The FAA reviewed a number of flights of varying distances, and compared the doses that would be received from cosmic radiation with that received by crewmembers from shipments of radioactive cargo of all kinds (FAA 1990).

Multiple Shipments

Total crew doses and risks were also determined for multiple shipments of HEU. Assuming a shipment of 5,000 kilograms (11,000 pounds) of HEU over a period of 10 years, the total number of shipments would range from 50, assuming all shipments were military shipments at 100 kilograms (220 pounds) HEU per shipment, to 1,000, assuming all shipments were commercial cargo shipments at 5 kilograms (11 pounds) HEU per shipment. The average annual number of shipments over 10 years would range from 5 to 100. However, there may be years in which a larger than average number of shipments could occur, and this possibility is also considered.

[22] *Cosmic radiation is meant as a general description for two principal sources of natural radiation during flight: (1) galactic cosmic rays, which are always present; and (2) solar energetic particle events, sometimes called solar cosmic ray events, which occur sporadically (NOAA 2000).*

Table 4–5 lists total crew doses and risks for shipping 100 kilograms (220 pounds) of HEU by either military or commercial aircraft, again assuming all flights are at extreme distances. The number of flights could range from one to 20 to transport this quantity of HEU, depending on the transportation mode.

Table 4–6 presents doses and risks for all members of all flight crews for four situations: (1) shipment of HEU at the annual average, (2) shipment of HEU at double the annual average, (3) shipment of HEU at triple the annual average, and (4) shipment of all HEU over a period of 10 years. Table 4–6 also presents the total doses that could occur to all members of the flight crews from cosmic radiation, using the same assumptions as those for Table 4–5. These doses and risks should be considered as ranges. For example, the total dose to crewmembers for shipment of 500 kilograms (1,100 pounds) of HEU may range from 0.020 person-rem to 0.11 person-rem, depending on the mix of commercial and military transport aircraft used for the shipments and on the types of packaging used. The quantities of HEU that may be transported in each shipment may also be different from those assumed. For example, if each military shipment only contained 50 kilograms (110 pounds) of HEU, 10 military flights would be required to ship 500 kilograms (1,100 pounds) rather than five. However, the dose to the crew would be somewhat smaller because the quantity of material shipped would be smaller. Assuming the dose rates per hour were about the same as those assuming 100-kilogram (220-pound) shipments, the total crew dose would rise to 0.040 to 0.056 person-rem. The total doses and risks from shipping the HEU would be smaller than those received from cosmic radiation.

The possibility that an individual crewmember could receive radiation doses from multiple shipments of HEU in a single year was also evaluated. The estimated doses are of interest in comparison to the annual limits on radiation doses to workers and members of the public, as codified in NRC regulations (10 CFR 20) and DOE regulations and orders (10 CFR 835, DOE 5400.5).

It is not possible to be precise about the doses that such a crewmember might receive. However, it may be demonstrated that no crewmember would be likely to receive a dose from the radioactive cargo (as opposed to cosmic radiation) in excess of 100 millirem in a year.

First, most shipments would not cover extreme distances. Most shipments would involve flight times far smaller than the assumed 33 to 34 hours flight time.

Second, it is unlikely that the same crew would be present for more than a few flights in a single year. For example, different commercial carriers (i.e., different crew populations) would be used depending on the transportation route. Flights may arrive from numerous starting points all around the world, resulting in shipments being carried by different cargo carriers and crews.

Third, because of the quantity of material carried, the largest doses to aircrew members per individual flight would be for military flights carrying IAEA Category I quantities of nuclear material. For these flights, it is standard operating procedure for shipments to be accompanied by radiological control technicians who would monitor package radiation levels, confirm that package radiation levels were within prescribed limits, and take whatever precautions that would be necessary to assure that crew doses from the packages would be as low as reasonably achievable (ALARA).

Table 4–5 Aircrew Doses and Risks for Shipping 100 Kilograms (220 pounds) of Highly Enriched Uranium

Transport Mode and HEU Mass	*Number of Flights*	*Package*	*Individual Dose and Risk*		*Total Crew Dose and Risk*		*Individual Cosmic Radiation Dose and Risk*		*Total Crew Cosmic Radiation Dose and Risk*	
			Dose (rem)	*Risk (LCF)* [b]	*Dose (person-rem)* [a]	*Risk (LCF)* [b]	*Dose (rem)* [c]	*Risk (LCF)* [b]	*Dose (person-rem)* [a,c]	*Risk (LCF)* [b]
Military 100 kilograms	1	TN-BGC1	0.000513	3.08×10^{-7}	0.00565	3.39×10^{-6}	0.00150	9.00×10^{-6}	0.165	9.90×10^{-5}
	1	ES-2100	0.000364	2.18×10^{-7}	0.00400	2.40×10^{-6}	0.00150	9.00×10^{-6}	0.165	9.90×10^{-5}
Military 50 kilograms	2	TN-BGC1	0.00103	6.16×10^{-7}	0.0113	6.78×10^{-6}	0.00300	1.80×10^{-5}	0.330	1.98×10^{-4}
	2	ES-2100	0.000728	4.37×10^{-7}	0.00800	4.80×10^{-6}	0.00300	1.80×10^{-5}	0.330	1.98×10^{-4}
Commercial 5 kilograms	20	TN-BGC1	0.00558	3.35×10^{-6}	0.0223	1.34×10^{-5}	0.288	1.73×10^{-4}	1.15	6.91×10^{-4}
	20	ES-2100	0.00347	2.08×10^{-6}	0.0139	8.32×10^{-6}	0.288	1.73×10^{-4}	1.15	6.91×10^{-4}

HEU = highly enriched uranium, LCF = latent cancer fatality.

[a] Crew sizes were assumed to be 11 for military flights and 4 for commercial flights.

[b] LCFs were determined by assuming 0.0006 LCF per rem.

[c] Cosmic radiation doses were estimated assuming a dose rate of 0.0006 rem (0.6 millirem) per hour.

Note: Doses and risks from HEU shipments were determined based on a total flight time of 34 hours for a military flight and 33 hours for a commercial flight. Doses from cosmic radiation were determined based on an airborne time of 25 hours for a military flight and 24 hours for a commercial flight. For the nine hours assumed to be spent on the ground during either commercial or military flights, aircrew were conservatively assumed to not leave the aircraft. Crew sizes were 11 for military aircraft and 4 for commercial aircraft.
To convert kilograms to pounds, multiply by 2.2.

Table 4–6 Total Dose and Risk to Flight Crews for Multiple Shipments

Condition	*Highly Enriched Uranium Shipped (kilograms)*	*Mode*	*Number of Flights*	*Package*	*Total Crew – HEU Packages*		*Total Crew – Cosmic Radiation*	
					Dose (person-rem)	*Risk (LCF)* [a]	*Dose (person-rem)*	*Risk (LCF)* [a]
Average Annual Quantity of HEU	500	Military [b]	5	TN-BGC1	0.0282	1.69×10^{-5}	0.825	4.95×10^{-4}
			5	ES-2100	0.0200	1.20×10^{-5}	0.825	4.95×10^{-4}
	500	Commercial	100	TN-BGC1	0.112	6.69×10^{-5}	5.76	3.46×10^{-3}
			100	ES-2100	0.0693	4.16×10^{-5}	5.76	3.46×10^{-3}
Double Annual Average Quantity	1,000	Military [b]	10	TN-BGC1	0.0565	3.39×10^{-5}	1.65	9.90×10^{-4}
			10	ES-2100	0.0400	2.40×10^{-5}	1.65	9.90×10^{-4}
	1,000	Commercial	200	TN-BGC1	0.223	1.34×10^{-4}	11.5	6.91×10^{-3}
			200	ES-2100	0.139	8.32×10^{-5}	11.5	6.91×10^{-3}
Triple Annual Average Quantity	1,500	Military [b]	15	TN-BGC1	0.0847	5.08×10^{-5}	2.48	1.49×10^{-3}
			15	ES-2100	0.0600	3.60×10^{-5}	2.48	1.49×10^{-3}
	1,500	Commercial	300	TN-BGC1	0.335	2.01×10^{-4}	17.3	0.0104
			300	ES-2100	0.208	1.25×10^{-4}	17.3	0.0104
Total 10-Year Quantity Shipped	5,000	Military [b]	50	TN-BGC1	0.282	1.69×10^{-4}	8.25	4.95×10^{-3}
			50	ES-2100	0.200	1.20×10^{-4}	8.25	4.95×10^{-3}
	5,000	Commercial	1000	TN-BGC1	1.12	6.69×10^{-4}	57.6	0.0346
			1000	ES-2100	0.693	4.16×10^{-4}	57.6	0.0346

HEU = highly enriched uranium, LCF = latent cancer fatality.

[a] LCFs were determined based on a risk of 0.0006 LCF per rem.

[b] The number of flights, doses, and risks are presented for 100-kilogram (220 pound) military shipments of HEU. If the military shipments were limited to 50-kilograms (110 pounds) each, the number of military flights and doses and risks to military aircrew would be about twice those shown in the table.

Note: To convert kilograms to pounds, multiply by 2.2.

Fourth, there is a practical limit to the annual number of flight hours that may be sustained. In a 1990 study, the FAA estimated that a representative work year for a member of a commercial aircrew would be 950 total hours (FAA 1990). This work year begins when the aircrew member's first flight in a one-year period leaves the terminal before takeoff and ends when the aircrew member's last flight in the one-year period reaches the terminal after landing. Based on safety concerns, crew flight duty times are limited on a monthly and annual basis. The monthly and annual limits that may apply to an aircrew may vary depending on factors such as the type of aircraft flown (e.g., cargo vs. passenger), the imposition of requirements and guidance by international and national regulatory (e.g., FAA) and trade organizations (e.g., IATA), and on collective bargaining agreements with air carriers. It appears, however, that few flight personnel would sustain more than about 1,000 flight hours in a year.

Assuming 1,000 airborne hours for both military and commercial aircrews, plus an additional 300 hours on the ground for refueling and other functions, the maximum dose to an individual crewmember, assuming that all flight hours involve HEU shipments at the assumed package radiation dose rate of 1 millirem per hour at 1 meter, would be about 20 millirem for a military crewmember and about 11 millirem for a commercial crewmember.[23] These doses were determined assuming the current practice of the existing procedures of placing packages containing radioactive material at the rear of the aircraft and away from the flight crew. However, historical experience is that 1-meter dose rates from shipped packages of HEU have been much smaller than 1 millirem per hour. Assuming a dose rate of 0.2 millirem per hour at 1 meter (3.3 feet), which is the maximum dose rate that has been historically observed (DOE 2006c, 2006d), the radiation dose from the HEU cargo assuming 1,300 hours of exposure to the radioactive cargo would be 4 millirem for a military aircrew member and 2.2 millirem to a commercial aircrew member.

Therefore, provided that current shipment practices and historical package radiation levels continue, no aircrew member would be likely to receive a radiation dose from exposure to the HEU cargo exceeding 100 millirem in a year. It may be possible for larger doses than those analyzed if transport conditions were significantly different from those modeled. Such conditions are the use of aircraft having different configurations or a change in package loading procedures, each of which could result in significant reductions in typical crew-to-package distances. For military shipments, which have the potential for the largest doses to individual crewmembers, standard NNSA practice is to include radiological control technicians with the flights (DOE 2006b). These radiation technicians would act to reduce possible doses experienced by the aircrew to ALARA levels.

FAA guidance for commercial aircrews is that occupational radiation exposures from cosmic radiation and other sources, including radioactive cargo, should be limited to 5 rem in a single year, or 2 rem per year as averaged over five years (FAA 2003). These radiation dose limits are the same as those imposed by NRC and DOE for occupational radiation protection. Military limits for occupational radiation protection are consistent with FAA guidance, as well as NRC and DOE requirements (DOD 1996).

4.2.3 Impacts from Transfer at a United States Airport

At the destination airport, the required number of trucks would be parked at a secure location awaiting the arrival of the aircraft. Upon arrival, the packages of HEU would be unloaded from the aircraft and loaded onto the trucks. The individuals who unload and load packages would receive some radiological exposure. The dose to these individuals would be a function of exposure time and their proximity to the package or the package array. It was assumed that activities at a military airbase for handling package arrays would take twice as long as activities at a commercial airport for handling one or a few packages.

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[23] Note that 1,000 airborne hours in a single year would result in a dose from cosmic radiation of roughly 600 millirem, which is far larger than that received from the radioactive cargo.

Because these activities would be performed in secure areas, and distant from locations occupied by members of the public, public doses under incident-free conditions would be negligible.

In the process of transferring packages from the aircraft to the truck, there is a possibility of an environmental release of a small amount of uranium oxide powder if a handling accident breached a package (e.g., a puncture from a misguided forklift tine). The material release would lead to local contamination having a very low potential hazard to the workers involved. Because the transfer of packages would be done in an open air or semi-open air environment, any release would be dispersed by ambient air currents leading to a very small and localized concentration of uranium in the air that workers might inhale. The ambient air concentration of HEU to which a worker could be exposed would be a function of many variables, such as wind speed, wind direction, worker location, degree of damage to the package, and response to the damage. Because the air concentration would be dependent on so many variables, a qualitative dose assessment was performed. Personnel familiar with the contents of the containers would provide oversight of the transfer, so that if there was a mishandling incident, actions to contain the material and mitigate any release would lead to very small consequences to the environment or workers. The consequences to noninvolved workers 100 meters (330 feet) from the incident and beyond would be orders of magnitude smaller than those of the involved workers. The public doses from potential incidents during handling activities also would be extremely small and would be bounded by the evaluated aircraft landing-stall-fire accident that would release much more material (see Section 4.2.4).

4.2.3.1 Commercial Air Cargo Transport – Impacts from Individual Shipments

The estimated incident-free handling dose to a representative worker is based on the assumption that unloading or loading activities would take about one hour for a 5-kilogram (11-pound) shipment of HEU. The dose to a representative worker, conservatively assuming that airplane unloading and truck loading are being done by the same person, standing at a distance between one to five meters (3.3 to 16.4 feet) from the package, would be a maximum of 0.23 millirem. Assuming that noninvolved workers and guards are approximately 10 meters (33 feet) from any packages, the dose to a representative individual would be 0.017 millirem. Using a dose-to-risk conversion factor of 0.0006 LCF per person-rem, the risks to a worker handling packages and any nearby worker (e.g., guards or other personnel) would be 1.4×10^{-7} and 1.0×10^{-8} LCF, respectively (about 1 chance in 7.25 million and about 1 chance in 100 million). Assuming that measurable radiation doses are received by two workers handling packages, and by three noninvolved workers and guards, the total collective worker dose and risk would be 5.11×10^{-4} person-rem and 3.1×10^{-7} LCF (about 1 chance in 3.2 million).

4.2.3.2 Military Air Cargo Transport – Impacts from Individual Shipments

The estimated incident-free handling dose to a representative worker was based on the assumption that unloading or loading activities at a military base would take about two hours for a 100-kilogram (220 pound) shipment of HEU. The dose to a representative worker, conservatively assuming that airplane unloading and truck loading would be done by the same person, standing at a distance between one to five meters (3.3 to 16.4 feet) from the package array, would be about 1.4 millirem per hour, or a maximum of 2.8 millirem for two hours of work. Assuming that noninvolved workers and guards are approximately 10 meters (33 feet) away from any packages, the dose to a representative individual would be 0.1 millirem per hour, or 0.2 millirem for two hours of work. (The higher dose for a military cargo operation than for a commercial cargo operation is due to larger characteristic dimensions associated with the package array as compared to an individual package in a commercial cargo.) Using a dose-to-risk conversion factor of 0.0006 LCF per person-rem, the risks to a single worker handling packages and any other nearby worker (e.g., guards or other personnel) would be 1.7×10^{-6} and 1.2×10^{-7} LCF (about 1 chance in 595,000 and 1 chance in 8.3 million), respectively, for unloading 100 kilograms (220 pounds) of HEU. Assuming that measurable radiation doses are received by two workers handling packages, and by three noninvolved workers and guards, the total dose and risk for all workers would be 0.0062 person-rem and 3.7×10^{-6} LCF (about 1 chance in 268,000), respectively.

Doses and risks for handling smaller quantities of HEU would be less than those presented above. Assuming a 50-kilogram (110-pound) shipment of HEU, the dose to a representative worker would be 0.93 millirem per hour, while the dose to a noninvolved worker or guard would be 0.048 millirem per hour. Assuming that unloading and transfer operations would again require two hours to complete, and the same dose-to-risk conversion factor, the doses and risks would be 1.3 millirem (7.8×10^{-7} LCF, or about 1 chance in 1.28 million) for a representative worker and 0.096 millirem (5.8×10^{-8} LCF, or about 1 chance in 17 million) for a noninvolved worker or guard. Again assuming that measurable radiation doses are received by two workers handling packages and by three noninvolved workers and guards, the total dose and risk for all workers would be 0.0029 person-rem and 1.7×10^{-6} LCF (about 1 chance in 580,000), respectively.

4.2.3.3 Impacts from Multiple Shipments of HEU

Total work crew doses and risks were determined for multiple shipments of HEU. The total number of shipments over 10 years would range from 50 (assuming all shipments were military shipments at 100 kilograms (220 pounds) of HEU per shipment) to 1,000 (assuming all shipments were commercial cargo shipments at 5 kilograms (11 pounds) of HEU per shipment). The average number of shipments over 10 years would range from 5 to 100 per year, but there may be years in which a larger than average number of shipments could occur.

Table 4–7 presents doses and risks for cargo handlers assuming shipment of 100 kilograms of HEU; the number of flights could range from 1 to 20 depending on the transportation mode.

Table 4–7 Cargo Handler Doses and Risks for Shipping 100 Kilograms of Highly Enriched Uranium

Transport Mode	*Number of Flights*	*Individual Cargo Handler*		*Individual Guard and Noninvolved Worker*		*Total Ground Crew*	
		Dose (rem)	*Risk (LCF)* [b]	*Dose (rem)*	*Risk (LCF)* [b]	*Dose (person-rem)*	*Risk (LCF)* [b]
Military 100 kilograms	1	0.0028	1.68×10^{-6}	0.0002	1.20×10^{-7}	0.0062	3.72×10^{-6}
Military 50 kilograms	2	0.0026	1.56×10^{-6}	0.000192	1.15×10^{-7}	0.0058	3.48×10^{-6}
Commercial 5 kilograms	20[a]	0.0046	2.76×10^{-6}	0.00034	2.04×10^{-7}	0.0102	6.12×10^{-6}

rem = roentgen equivalent man, LCF = latent cancer fatality.
[a] It is unlikely that the same cargo handling crew would be involved with this many HEU shipments.
[b] LCFs were estimated assuming a risk of 0.0006 LCF per rem.
Note: To convert kilograms to pounds, multiply by 2.2.

Table 4–8 presents total doses and risks for four situations: (1) shipment of HEU at the annual average, (2) shipment of HEU at double the annual average, (3) shipment of HEU at triple the annual average, and (4) shipment of all HEU over a period of 10 years.

Again, individual doses from multiple shipments of HEU were considered. It is difficult to estimate total annual doses that may be received by an air cargo handler or other guards or workers because shipments may arrive at a variety of airports and airbases. Practices for radiation protection may differ depending on whether the shipment is to a commercial air cargo facility or a military airbase.

Table 4–8 Total Doses and Risks to Ground Personnel for Multiple Highly Enriched Uranium Shipments

Condition Illustrated	*HEU shipped (kilograms)*	*Transport Mode (kilograms per shipment)*	*Number of Flights*	*Total Crew Dose (person-rem)* [d]	*Total Crew Risk (LCF)* [e]
Annual Average	500	Military (100)	5 [a]	0.030	1.86×10^{-5}
	500	Military (50)	10 [b]	0.029	1.74×10^{-5}
	500	Commercial (5)	100 [c]	0.051	3.06×10^{-5}
Double Annual Average	1,000	Military (100)	10 [a]	0.062	3.72×10^{-5}
	1,000	Military (50)	20 [b]	0.058	3.48×10^{-5}
	1,000	Commercial (5)	200 [c]	0.102	6.12×10^{-5}
Triple Annual Average	1,500	Military (100)	15 [a]	0.093	5.58×10^{-5}
	1,500	Military (50)	30 [b]	0.087	5.22×10^{-5}
	1,500	Commercial (5)	300 [c]	0.153	9.18×10^{-5}
10-Year Total	5,000	Military (100)	50 [a]	0.31	1.86×10^{-4}
	5,000	Military (50)	100 [b]	0.29	1.74×10^{-4}
	5,000	Commercial (5)	1,000 [c]	0.51	3.06×10^{-4}

HEU = highly enriched uranium, LCF = latent cancer fatality.
[a] Assuming each flight carries 100 kilograms (220 pounds) of HEU.
[b] Assuming each flight carries 50 kilograms (110 pounds) of HEU.
[c] Assuming each flight carries 5 kilograms (11 pounds) of HEU.
[d] Assuming two representative workers unloading HEU plus three guards and noninvolved workers.
[e] LCFs were determined assuming 0.0006 LCF per rem.
Note: To convert kilograms to pounds, multiply by 2.2.

Persons involved in cargo handling operations at commercial air cargo facilities routinely handle shipments of hazardous materials, including radioactive materials (generally shipments containing short-lived radionuclides used for medical applications). These airport workers are normally not monitored for radiation exposure. One reason is that compliance with transportation requirements, including compliance with package radiation dose rate limits, are confirmed before the packages are loaded on the airplane. At a large airport, there would be numerous persons involved in cargo handling operations in several different work crews, depending on the variety of air cargo carriers that use the airport. Commercial cargo handling operations may go on for 24 hours per day, which would involve three separate shifts of air cargo handling crews. Even if a large number of flights containing HEU landed at the same airport, it is unlikely that any individual would be directly involved with more than a few shipments of HEU.

If only a few military airbases were used, it may be theoretically possible for a single individual to be involved in a number of shipments in a single year. However, for military shipments of HEU, it is standard practice to receive the materials under the direction of trained radiological technicians who would monitor the operations, including radiation and possible contamination levels. As needed, loading crews would be provided with radiation detectors that would be collected after the end of operations. Information about exposure would be tracked for radiological tracking purposes (DOE 2006b). The allowable occupational radiation dose limit for military radiological workers is the same as that used by DOE and recommended for flight crews by FAA.

Assuming that the same crews are responsible for up to 10 shipments of HEU in a year, the total dose to an individual worker (assuming that this individual always received the largest dose among crewmembers) would be 28 millirem (risk of 1.7×10^{-5} LCF, about 1 chance in 59,500) for military shipments (assuming all 100-kilogram (220 pound) HEU shipments) and 13 millirem (risk of

7.8×10^{-6} LCF, about 1 chance in 128,000) for military shipments (assuming all 50-kilogram (110 pound) HEU shipments). The total individual dose and risk for ten 5-kilogram (11 pound) commercial shipments would be 2.3 millirem (risk of 1.4×10^{-6} LCF, about 1 chance in 724,000) for commercial shipments. These doses are all smaller than DOE's annual radiation dose limit of 100 millirem for members of the public.

Radiation levels associated with shipments of HEU are typically much lower than those that are assumed for this SA. It was assumed that the HEU packages have average external radiation dose levels equal to one millirem per hour at one meter (3.3 feet) from any package surfaces. However, past shipments of HEU have measured no more than about 0.2 millirem per hour at one meter (3.3 feet), or a factor of five smaller (see Section 4.2.2). Even under the conservative assumption that all shipments of HEU arrive at a single airport or airbase, and the equally conservative assumption that the same member of the work crew handles all shipped packages, the total dose would be roughly 46 millirem to a crewmember handling all 5-kilogram (11-pound) commercial shipments, 26 millirem to a crewmember handling all 50-kilogram (110-pound) military shipments, or 28 millirem to a crewmember handling all 100-kilogram (220-pound) military shipments. Therefore, the estimated 10-year doses would all be smaller than the NRC and DOE annual radiation dose limit of 100 millirem in a year to a member of the public. Hence, even if all shipments arrive in a single year, a member of a cargo handling crew would not be expected to receive a radiation dose exceeding the NRC and DOE annual limit for members of the public.

4.2.4 Impacts from Air Transportation Accidents

4.2.4.1 Impacts from Commercial Air Transportation Accidents

Landing-Stall-Fire Accidents

It is possible, although very unlikely, that an air shipment containing unirradiated HEU could have an accident at an airport. The maximum consequence accident would be one where an aircraft stalls and crashes while attempting to land, resulting in a fire from the remaining aircraft fuel. The nonradiological consequences of such an accident would be no different than those associated with an aircraft of comparable size that did not contain HEU.

The assumption of a landing-stall-fire accident provides a conservative analysis of air shipment accident environmental impacts. Postulated terrorist attacks on HEU shipments are expected to be bounded by the landing-stall-fire accident because of its conservative assumptions and methodology.

For radiological impacts, this SA follows a similar method as that used in the *Russian HEU Transport EA* (DOE 2004a) and the *Foreign Research Reactor EA* (DOE 2005a). In these references, and in this SA, the following assumptions were made:

- The impact and fire cause failure of all the transport packages, exposing all of the HEU to the fire.

- The radiological impacts are independent of the type of plane. The radiological impacts are a function of the plume heat energy, plume height, plume time duration, the fraction of the shipped uranium released to the environment as respirable particles, the population distribution surrounding the airport, and average meteorological conditions.

Radiological impacts were then calculated as follows:

- Population doses and risks were calculated for the population estimated to be within 80 kilometers (50 miles) of the accident site (including estimated population growth to the year 2020 of 21 percent for the commercial airport and 46 percent for the military airbase).

- Individual doses and risks were calculated for the MEI, a hypothetical individual member of the public who would receive the maximum dose from an accident, and who was assumed to be located 1.6 kilometers (one mile) downwind from the accident site.

- Individual doses and risks were calculated for a noninvolved worker,[24] a worker at the airfield who is not part of the HEU transportation activity, and who was assumed to be located 100 meters (328 feet) downwind from the accident site.

The analysis in this SA is conducted using the MELCOR Accident Consequence Code System, Revision 2, Version 1.13.1 (MACCS2) (NRC 1998). This standard version of MACCS2 has been extensively used in numerous NEPA analyses and was not modified for calculations in support of this SA. Doses were calculated due to inhalation of airborne material and external exposure to the passing plume. This represents the major portion of the dose that an individual would receive as a result of an aircraft accident. The longer-term effects of radioactive material deposited on the ground after a postulated accident, including the resuspension and subsequent inhalation of radioactive material and the ingestion of contaminated crops, were not modeled. Resuspension pathways are typically much smaller than those involving inhalation of airborne material and external exposure to the passing plume. Pathways involving ingestion of contaminated crops would be controlled. (Assuming such an accident occurred, a radiological response action would occur. Both short- and long-term potential impacts [e.g., from food consumption] would be assessed and interdicted if they exceeded established requirements.) Hence, the deposition velocity of the radioactive material was set to zero for purposes of the MACCS2 model, so that material that might otherwise be deposited on surfaces remains airborne and available for inhalation. This adds conservatism to inhalation doses that can become considerable at large distances. Thus, the method used in this assessment is conservative compared with dose results that would be calculated if deposition and resuspension were taken into account.

The population distribution for each airport was based on the 2000 U.S. Census (DOC 2002, 2005). These data were fitted to a polar coordinate grid having 16 angular sectors aligned with the 16 compass directions, with radial intervals extending outward to 80 kilometers (50 miles). Based on a previous EA for air transport of unirradiated uranium in research reactor fuel (DOE 2005a), the consequences and risks to the 80-kilometer (50-mile) radius population around JFK International Airport in New York City were larger than those at the large international civil airports in Atlanta, Chicago, Memphis, and Miami. Because this SA is intended to be applicable to all possible civilian airports in the United States for receipt of shipments of HEU, a survey of metropolitan area populations was performed. It showed that, along with JFK International Airport, Newark Liberty International Airport in Newark, New Jersey, and Los Angeles International Airport in Los Angeles, California, have the largest 80-kilometer (50-mile) radius populations. The offsite population within 80 kilometers (50 miles) was estimated to be 13,342,180 persons at Los Angeles International Airport; 18,091,446 persons at Newark Liberty International Airport; and 18,079,725 persons at JFK International Airport. Los-Angeles International Airport was included, even though it appears to have a much lower population than JFK International and Newark Liberty International Airports, because the population dose is affected not only by the magnitude of the 80-kilometer (50-mile) radius population, but the relative population distribution as a function of distance inside this radius.

A single bounding source term was developed to envelope all the shipments considered in this SA. This source term was based on an evaluation of the largest radioactive release expected from any HEU shipment. For a high-temperature fire fueled by aircraft fuel at a civil airport, the aircraft was conservatively assumed to contain 10 kilograms (22 pounds) of HEU, which is twice the maximum

[24] *The impacts on involved workers were addressed qualitatively because no adequate method exists for calculating meaningful consequences at or near the location where the accident might occur. Involved workers would also be fully trained in emergency procedures, including potential accidents.*

expected cargo limit of 5 kilograms (11 pounds) for commercial transport. At a military airport using military aircraft, the aircraft was conservatively assumed to contain 100 kilograms (220 pounds) of HEU, which is twice the maximum expected cargo limit of 50 kilograms (110 pounds). No credit was taken for emergency response evacuations, temporary relocation, or sheltering of the general public.

The IAEA definition of unirradiated uranium allows for a small inventory of uranium-236, plutonium, and fission products (IAEA 2005). The IAEA unirradiated uranium definition bounds the Y-12 Complex acceptance criteria. The maximum allowable inventory of these radionuclides from the IAEA definition of unirradiated uranium was used to calculate their maximum possible content within the HEU.[25] Because it has the largest inhalation effective dose conversion factor (the radiation dose to a person from inhaling a given activity of the specific radioisotope), plutonium-239 was used to represent all possible plutonium radioisotopes (EPA 1988). Fission products can potentially consist of hundreds of radioisotopes. Based on a previous EA for the transport of unirradiated research reactor fuel (DOE 2005a), the fission product content of the unirradiated nuclear fuel was simulated as 100 percent iodine-129. The bounding respirable source term used in MACCS2 calculations to envelop all commercial fuel shipments is presented in **Table 4–9**. This source term is based on the description in Chapter 2 for HEU and the assumed absence of any surface radioactive contamination.

Table 4–9 Bounding Respirable Highly Enriched Uranium Radioactive Source Term for High-Temperature Fire Resulting from Landing-Stall Crash

Radioisotope	*Uranium-235*	*Uranium-238*	*Uranium-236 and Uranium-234*	*Plutonium-239*	*Iodine-129*
Respirable Airborne Source Term (curies) – Commercial Aircraft and Airport (10 kilograms HEU as uranium oxide powder)	1.74×10^{-4}	1.50×10^{-6}	3.83×10^{-3}	4.3×10^{-6}	1.93×10^{-2}
Respirable Airborne Source Term (curies) – Military Aircraft and Airport (100 kilograms HEU as uranium oxide powder)	1.74×10^{-3}	1.50×10^{-5}	3.83×10^{-2}	4.3×10^{-5}	1.93×10^{-1}

HEU = highly enriched uranium.
Note: To convert kilograms to pounds, multiply by 2.2.

A single bounding aircraft accident was analyzed for all commercial air shipments of HEU powder to the three commercial airports considered in this SA. This accident could occur regardless of the type of aircraft used to transport the HEU (although the frequency of occurrence is different for commercial cargo aircraft and military cargo aircraft). Also, such an accident was assumed to occur at any of the airports under consideration. MACCS2 input parameters were all set to maximize the calculated dose and produce a conservative and bounding radiological consequence to the public. Key input parameters that were set to result in higher calculated doses included plume heat energy, plume height, plume time duration, and the fraction of available radioactive material that was released to the environment as respirable particles.

Plume heat energy is a parameter that significantly affects the calculated doses to the public, MEI, and noninvolved worker. Because the 10-year air transport of HEU may be by military or commercial aircraft having different designs, a sensitivity study was performed using the MACCS2 computer code to evaluate the effect of plume energy on calculated doses. For all three receptors (e.g., 80-kilometer or 50-mile radius population, MEI, and noninvolved worker), the calculated dose reached a maximum value at and below a plume energy of 1×10^6 watts. Above a plume energy of 1×10^6 watts, the calculated dose

[25] See Section 2.0 for the IAEA definition specifying the limiting allowable quantities of uranium-236, plutonium, and fission products within unirradiated fuel.

decreased. Therefore, for conservatism, and to envelope all possible future military and commercial aircraft, the MACCS2 calculations were all performed with a plume energy of 1×10^{6} watts.

A maximum consequence landing-stall-fire accident was assumed to have an equal chance of occurring at any of the airports. Air transportation of the unirradiated HEU may use U.S. or foreign cargo aircraft. DOE has developed aircraft landing crash rates for different types of aircraft (DOE 2006a), which provides the value of 2.8×10^{-7} per landing for commercial air carriers, or about 1 chance in 3.6 million, and 1.6×10^{-6} per landing for large military aircraft, or about 1 chance in 625,000.

Although the chance of an accident at each commercial airport was assumed to be identical, the total population dose would be different because of different population sizes and distributions (**Table 4–10**). The largest population dose was calculated for the 18.1 million persons projected to be within an 80-kilometer (50-mile) radius of JFK International Airport. This dose is 8.93 person-rem (0.00536 LCF) using a projected uniform increase of 21 percent in the 80-kilometer (50-mile) radius population between the years 2000 and 2020. The largest population dose and associated LCF at JFK International Airport is equivalent to about 1 chance in 200 that any excess cancer fatalities would occur in the surrounding 80-kilometer (50-mile) radius population. The risk of such a cancer fatality is much smaller (about 1 chance in 667 million) considering the 2.8×10^{-7} probability of accident occurrence. The accident dose to the MEI, located at one mile from the plume release site, is 0.07 millirem and is identical for all airports because it is not a function of the site's 80-kilometer (50-mile) radius population distribution. The MEI dose would result in 4.2×10^{-8} LCF, which is about 1 chance in 24 million that an individual would develop a fatal cancer and is also identical for all commercial airports.

Table 4–10 Air Transport Landing-Stall-Fire Accident Radiological Consequences from Bounding Airport Accident Involving Transport of 10 Kilograms of Highly Enriched Uranium

Impacts Calculated	*Los Angeles International Airport*	*Newark Liberty International Airport*	*John F. Kennedy International Airport*
80-kilometer (50-mile) radius population [a]	13,342,180	18,091,446	18,079,725
Accident probability (per flight)	2.8×10^{-7}	2.8×10^{-7}	2.8×10^{-7}
80-kilometer (50-mile) total population dose (person-rem), including 1.21 factor for population increase between 2000 and 2020	6.84	8.25	9.01
80-kilometer (50-mile) population LCF [b]	4.10×10^{-3}	4.95×10^{-3}	5.41×10^{-3}
80-kilometer (50-mile) population risk [c]	1.15×10^{-9}	1.39×10^{-9}	1.52×10^{-9}
MEI dose at 1.6 kilometers (1 mile) (millirem)	0.0704	0.0704	0.0704
MEI [d] LCF [b]	4.2×10^{-8}	4.2×10^{-8}	4.2×10^{-8}
MEI risk [c]	1.18×10^{-14}	1.18×10^{-14}	1.18×10^{-14}
Noninvolved worker [e] dose at 100 meters (328 feet) (millirem)	11.3	11.3	11.3
Noninvolved worker LCF [b]	6.78×10^{-6}	6.78×10^{-6}	6.78×10^{-6}
Noninvolved worker risk [c]	1.90×10^{-12}	1.90×10^{-12}	1.90×10^{-12}

MEI = maximally exposed individual, LCF = latent cancer fatality, 1 rem = 1,000 millirem.
[a] Based on 2000 Census.
[b] LCFs are based on a risk factor of 0.0006 LCF per rem.
[c] Risk is calculated by multiplying the LCF by the accident probability of 2.8×10^{-7} per operation (landing).
[d] The MEI is located 1.6 kilometers (1 mile) downwind from the plume release site.
[e] The noninvolved worker is located 100 meters (328 feet) downwind from the plume release site.

A methodology to calculate the radiological consequence of a specific HEU air transport accident at a commercial airport is presented in Appendix A.

Inflight Accident Over U.S. Territory

The potential impacts of an inflight accident while over U.S. territory were evaluated in the *Project Sapphire EA* (DOE 1994). The analysis evaluated the impacts of a hypothetical inflight accident involving about 300 kilograms (660 pounds) of HEU on a generic, large urban area having a population of 5.21 million.[26] The inflight accident analysis projected a population dose of 15.6 person-rem. Assuming a risk factor of 0.0005 LCFs per rem, which was the risk factor used at the time of the EA, this dose would result in 7.8×10^{-3} LCFs in this population, corresponding to a chance of about one in 130 that a single LCF could occur resulting from this dose among the exposed population, assuming that the accident occurred. However, the probability of such an inflight accident occurring was judged to range from 6.7×10^{-10} to 2×10^{-9} (about 1 to 0.5 chances in a billion, respectively), depending on the time that the aircraft would spend over U.S. soil, which differed depending on the three alternative military airbases considered. Assuming an accident probability of 2×10^{-9}, the population risk would be 1.6×10^{-11} (about 1 chance in 63 billion).[27]

The maximum population dose consequences for an aircraft landing-stall-fire accident in this SA of 9.01 person-rem (5.41×10^{-3} LCF) is lower than the inflight accident consequences calculated in the *Project Sapphire EA* (DOE 1994) because of the much smaller mass of HEU and its associated radioisotope inventory associated with this SA. However, when the probability of an accident is considered (2.8×10^{-7} for a landing-stall-fire accident versus 2×10^{-9} for an inflight accident), the population risk calculated from the highest-consequence landing-stall-fire accident (1.52×10^{-9}) is larger than that addressed for an inflight accident (1.6×10^{-11}) in the *Project Sapphire EA* (DOE 1994). Therefore, when considering the probability of occurrence, the population risks from a landing-stall-fire accident are bounding over an inflight accident.

4.2.4.2 Impacts from Military Air Transportation Accidents

Possible impacts from a severe landing-stall-fire accident at a military airbase were assessed in this SA in the same manner as that discussed in Section 4.2.4.1 for shipment to three selected commercial airports. Similar to the approach taken for the *Foreign Reactor Fuel EA* (DOE 2005a), it was assumed that the HEU could be flown to any of a number of military airbases. To bound the possible impacts from a severe accident, a population distribution corresponding to that surrounding a military airbase in a densely populated area was assumed for the analysis. The results of this assessment are presented in **Table 4–11**.

The military aircraft accident MEI and noninvolved worker doses are ten times larger than those calculated for commercial airports, but have a higher total risk commensurate with the higher frequency of an aircraft stall-crash accident for military aircraft (1.6×10^{-6}), as compared to commercial cargo aircraft (2.8×10^{-7}) (DOE 2006a). The results are independent of unirradiated HEU shipping package design or aircraft design and would be the same for any military airbase.

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[26] *The total quantity of material shipped was 566 kilograms (1,250 pounds) of HEU. However, the HEU was transported in two aircraft, resulting in about 300 kilograms (660 pounds) of HEU per aircraft.*

[27] *The stated population risk of 7.8×10^{-4} LCF given in the Project Sapphire EA is in error. The correct value is 7.8×10^{-3} LCF as given above.*

Table 4–11 Human Health Impacts of a Severe Landing-Stall-Fire Accident during Air Transport of Highly Enriched Uranium (100 kilograms) to a Military Airbase

Impacts Calculated	***Calculated Values***
80-kilometer (50-mile) radius 2000 Census population [a]	763,394
Accident probability (per landing)	1.6×10^{-6}
Total population dose [b] (person-rem)	38.5
Population LCF [c]	0.023
80-kilometer (50-mile) population radiological risk [d]	3.70×10^{-8}
MEI dose [e] (millirem)	0.704
MEI LCF [c]	4.22×10^{-7}
MEI radiological risk [d]	6.75×10^{-13}
Noninvolved worker dose (millirem) [f]	113
Noninvolved worker LCF [c]	6.78×10^{-5}
Noninvolved worker radiological risk [d]	1.08×10^{-10}

MEI = maximally exposed individual, LCF = latent cancer fatality.
[a] For purposes of analysis, the population distribution was that of a military airbase near a large metropolitan area.
[b] 80-kilometer (50-mile) population dose includes a 1.46 multiplier to account for an assumed 50-mile radius population increase between the years 2000 and 2020.
[c] LCFs are based on a risk factor of 0.0006 per person-rem.
[d] Radiological risk includes consideration of the accident probability of 1.6×10^{-6} per operation (landing).
[e] The MEI is located 1.6 kilometers (1 mile) downwind from the plume release site.
[f] Noninvolved worker is located 100 meters (328 feet) downwind from the plume release site.
Note: 1 rem = 1,000 millirem.

A method to calculate the accident radiological consequences of a specific HEU air shipment to a military airbase is presented in Appendix A.

4.3 Ocean Transport

Although the bulk of the shipments of HEU would be by aircraft, shipments of HEU could occur by ocean vessel. The *FRR SNF EIS* addressed the environmental impacts of a proposed policy for United States acceptance of spent nuclear reactor fuel from several foreign countries (DOE 1996a). The 1996 Record of Decision for the policy indicated that unirradiated nuclear fuel (HEU or LEU) from eligible research reactors would be accepted as spent nuclear fuel (61 FR 25091). The *Russian HEU Transport EA* analyzed the shipment of 166 kilograms (365 pounds) of HEU by ocean vessel, and such shipment was determined not to constitute a major federal action significantly affecting the quality of the environment (DOE 2004a).[28] That assessment was used in this SA to address the potential impacts from shipment of HEU by ocean vessel.

4.3.1 Impacts on the Global Commons (Ocean)

Transporting the HEU by ocean vessel would annually add one to a few trips to the thousands of annual commercial and military vessel trips across the oceans of the world. Therefore, a ship (or a few ships) containing HEU would not have a significant impact on the global commons. It is possible that a ship containing HEU could pass through an area known to be routinely inhabited by the right whale, an endangered species. (There are two identified areas: one located mainly off the coast of Massachusetts and one located off the coasts of Florida and Georgia [66 FR 58066].) If the ship enters such an area, it would be required to contact the Mandatory Ship Reporting System operated by the United States Coast Guard and endorsed by the International Maritime Organization. Operation of this system is meant to

[28] *See Section 1.4.2.*

reduce the likelihood of a ship striking a right whale. The ship would report its name, call sign, location, course, speed, destination, and route. The system would respond to the ship with contact information on the latest data on whale sightings and avoidance procedures that could prevent a collision (DOE 2004a).

4.3.2 Impacts from Incident-Free Ocean Transport

There would be no radiological impacts to the public from incident-free transport of the HEU by ocean vessel. This is because of the distance that would be maintained between the packages of HEU and members of the public. The only radiation doses that may occur would be to members of the crew resulting from potential exposure to external radiation when in the vicinity of the HEU packages. Because the HEU would be in holds below the decks of the ships and at a distance from wheelhouses and quarters, the principal crew exposure would be to a crewmember who enters the hold, for example, to inspect the cargo.

The analysis presented in the *Russian HEU Transport EA* addressed shipment of 166 kilograms (365 pounds) of HEU on a voyage requiring 21 days. The analysis estimated a dose of 2 millirem (risk of 1.2×10^{-6} LCF, or about 1 chance in 830,000) to a member of the crew, assuming that the HEU was shipped in TN-BGC1 packages; and 1 millirem (risk of 6.0×10^{-7} LCF, or about 1 chance in 1.7 million), assuming shipment in ES-2100 packages. This member of the crew was assumed to require 15 minutes once a week to inspect the cargo, and that the dose rate for the packages of HEU was assumed to be 1 millirem per hour at one meter (3.3 feet) from the surfaces of the containers (DOE 2004a).

The analysis in that EA would bound the analysis for shipments of HEU contemplated for this SA. The total quantity of material analyzed in that EA was much larger than the maximum quantity considered for this SA. The package dose rate assumed for the EA analysis was one millirem per hour at one meter, which, as noted above, is about a factor of five larger than that observed from actual shipments of HEU to the Y-12 Complex. The length of the voyage was 21 days, which was consistent with that assumed in the *FRR SNF EIS* as an average length of voyage from receiving spent nuclear fuel from locations all around the world. The longest shipment considered in the *FRR SNF EIS* was 34 days (from Pakistan). Therefore, even if a shipment of HEU for this SA required 42 days to complete, which is twice the assumed time of voyage in the *Russian HEU Transport HEU*, and longer than the maximum voyage length considered in the *FRR SNF EIS*, the dose to a crewmember would be less than 2 millirem per voyage.[29]

If all 5,000 kilograms (11,000 pounds) of HEU were delivered by ship at 166 kilograms (365 pounds) of HEU per shipment, then about 15 shipments would be needed. Assuming the same persons were hypothetically involved with each shipment, the total dose and risk of an individual crew member would be less than 30 millirem (1.8×10^{-5} LCF, or about 1 chance in 56,000). These doses and risks correspond to an average package dose rate of 1 millirem per hour at 1 meter (3.3 feet), which is historically conservative by at least a factor of five, and an average voyage length of 21 days. Even if all 15 shipments occurred over a single year, no individual would receive a dose exceeding the NRC and DOE radiological limit of 100 millirem in a year for members of the public.

4.3.3 Impacts from Transfer at a Seaport to Transport Vehicles

At the seaport, the necessary number of trucks would be parked at a secure location awaiting the arrival of the ocean vessel. The mode of vehicle transport (exclusive use vehicle or SST/SGT) would depend on the quantity of HEU shipped. Upon arrival, the packages of HEU would be removed from the ship’s hold

[29] *The dose for a 42-day shipment, assuming a dose rate of 0.2 millirem per hour at one meter, based on historical experience with shipping HEU, would be (1/5 × 2 × 2 =) 0.8 millirem for shipment in TN-BGC1 packages, or (1/5 × 2 × 1 =) 0.4 millirem for shipment in ES-2100 packages.*

using a crane and placed on the dock. Workers would enter the hold, remove the tie-downs that secured the packages for the ocean voyage, and attach rigging to remove the packages from the hold. At dockside, the rigging would be removed, packages would be made ready, and the packages would be loaded and secured in the trucks.

Similar to the scenario of an unloading accident at airports and airbases, there is a possibility of an environmental release of a small amount of uranium powder if a handling accident breached a package while unloading the ship (i.e., a package is dropped or punctured). If this event occurred, the released material would lead to localized contamination having low potential hazards to the involved workers. A qualitative assessment of the impacts of such an accident is presented because the resulting radioactive air concentration is dependent on many uncertain variables, such as degree of damage to the package, wind speed, wind direction, and location of workers. Personnel familiar with the package contents would oversee the transfer of packages from the ship to the trucks. If there were an accident, actions to contain the material and mitigate the impacts would be taken. Consequences to the environment or workers are expected to be very small. The airborne release from a mishandling accident would be much smaller than the release from a ship collision at the dock involving a severe fire. Therefore, the consequences to the noninvolved workers and the population from any mishandling incident would be bounded by the ship accident at the dock.

Assuming incident-free transfer of the HEU containers to the vehicles, the only dose that would be significant would be to those persons directly involved in the transfer (loaders, guards, etc.). Members of the public would be too distant to receive measurable radiation exposures. The dose to an exposed worker would be a function of the exposure time and the distance from the packaged material. For the transfer of 166 kilograms (365 pounds) of HEU, the duration for unloading the HEU packages from the ship and securing them in the trucks was assumed to be one hour, with the most highly exposed worker being one meter (3.3 feet) from the packages. The dose to a crewmember unloading, inspecting, and reconfiguring packages for vehicle transport was estimated to be about 8 millirem, and the dose to a noninvolved worker, or a guard at a distance of about 10 meters from the packages, was estimated to be 0.4 millirem. The corresponding risks to the most highly exposed crewmember were 4.8×10^{-6} (about 1 chance in 210,000) and 2.4×10^{-7} (about 1 chance in 4.2 million) LCF, respectively. Radiological doses to members of the United States Coast Guard or other regulatory agencies inspecting the ship and cargo at the time of its arrival would be smaller than the doses to crewmembers (DOE 2004a).

If all 5,000 kilograms (11,000 pounds) of HEU were shipped by ocean vessel over the 10-year period considered in this SA, assuming that all shipments involved 166 kilograms (365 pounds) of HEU and the same dock workers were involved in all shipments, the total dose and risk to the most highly exposed worker and noninvolved worker would be about 120 millirem (7.2×10^{-5} LCF or about 1 chance in 14,000) and 6 millirem (2.4×10^{-6} LCF, or about 1 chance in 420,000), respectively. However, NNSA experience is that external dose levels for actual HEU shipments have historically been much smaller than one millirem at 1 meter (3.3 feet). Assuming a historical dose rate of 0.2 millirem per hour at 1 meter (3.3 feet), the total doses over 10 years, would be 24 millirem to the most highly exposed dock worker and 1.2 millirem to the noninvolved worker or guard. Hence, under these assumptions, no member of the dock worker crew would receive a total dose exceeding 100 millirem from all shipments over 10 years.

4.3.4 Impacts from Ocean Transportation Accidents

Impacts from a severe ship accident were determined in the *Russian HEU Transport EA* using the MACCS2 code. The shipment accident having the greatest impact was determined to occur at the port (either in the shipping channel or at the shipping dock), assuming a representative mid-Atlantic military port, such as the Norfolk Naval Station in Virginia or the Charleston Naval Weapons Station in South Carolina.

The population within 80 kilometers (50 miles) of the representative port was assumed to be about 1.7 million people. The MEI was assumed to be 0.6 kilometers (0.4 miles) from the accident release point and a noninvolved worker about 100 meters (328 feet) away.

The ship accident scenario involved another ship colliding with a ship transporting 166 kilograms (365 pounds) of HEU. The initial collision was assumed to cause damage to the ship and the HEU packages, resulting in release of radioactive materials. A subsequent fire was assumed to cause the release of additional radioactive material to the environment. As for the landing-stall-fire accident considered in this SA, the major impact of such an accident would be exposure to and inhalation of the passing plume. The projected doses and risks from this accident are summarized in **Table 4–12**.

Table 4–12 Summary of Radiological Doses and Risks Assessed for a Port Accident in the Russian HEU Transport Environmental Assessment

Accident Receptor	*Radiological Doses (rem or person-rem)*	*Radiological Risk per Accident (LCF)* [a]	*Radiological Risks Considering Accident Probability (LCF)* [b]
Collective Population	40.9 person-rem	0.025	1.2×10^{-10}
MEI [c]	0.00247 rem	1.5×10^{-5}	7.4×10^{-14}
Noninvolved Worker [c]	0.00338 rem	2.0×10^{-5}	1.0×10^{-13}

LCF = latent cancer fatality, MEI = maximally exposed individual.

[a] Risks were estimated in the Russian HEU Transport EA assuming 0.0006 LCFs per rem.

[b] The probability of a port shipping accident that breached the Type B packages assumed for the analysis was 5×10^{-9} per port entry.

[c] The MEI was assumed to be 0.6 kilometers (0.4 miles) from the point of the accident; the noninvolved worker was assumed to be 100 meters (328 feet) away.

Note: The impacts from the accident were assumed to be independent of the type of package considered in the analysis, either TN-BGC1 or ES-2100.

Source: DOE 2004a.

The projected impacts from this accident are larger than those assessed in this SA for air transport of HEU. One reason is that the quantity of HEU involved in this accident (166 kilograms or 365 pounds) is much larger than that assumed in this SA for commercial and military air transport. However, the probability of the accident at a seaport (5×10^{-9} per port entry) is smaller than that assumed for commercial air transport (2.8×10^{-7} per landing) or military air transport (1.6×10^{-6} per landing). Considering the probabilities of accidents occurring, the 80-kilometer (50-mile) population radiological risk for an accident at a seaport is smaller than that determined in this SA for a severe accident at a military airbase and larger than that determined in this SA for a severe accident at a commercial airport.

4.4 Additional Impacts

4.4.1 Additional Impacts from Air and Ocean Vessel Transport Operations

Shipment of the HEU would involve the use of existing infrastructure at airfields, dock facilities and roadways. Because there would be no construction or modification of airport or seaport facilities, there would be no land disturbance that could potentially affect biological resources, cultural resources, or geologic media. No water would be withdrawn from or discharged to surface water or groundwater. Neither would any water be withdrawn from or discharged to ocean or port waters beyond that needed for the normal operation of a ship. Shipment of the HEU would not have any effect on socioeconomic conditions at any of the analyzed locations. All work would be accomplished using existing personnel. Once at the airport, airbase or port of destination, the enriched uranium would be transferred from the aircraft or vessel to a waiting vehicle and shipped to the Y-12 Complex as expeditiously as possible. Hence, the duration of personnel involvement at the airport, airbase, or port facility would be a relatively small portion of any given year, avoiding the need to add to the workforce. Thousands of aircraft operations occur annually at large commercial airports and military airbases (for example, over 300,000 per year at JFK International Airport). Flights containing HEU would represent only a small fraction of this total. A similar statement can be made about ocean shipments of HEU.

Shipment of HEU would also not cause disproportionately high and adverse radiological risks to low-income or minority populations. Members of the public would be placed at little to no radiological risk during the normal operations considered in this SA because of the distances that would be maintained between the shipping packages and any member of the public. Radiological exposures would only occur to workers such as aircraft crewmembers.

Members of the public would not be placed at significant radiological risk in the event of severe accidents at or near the points of entry to the United States. In the unlikely event of an aircraft landing-stall-fire accident, the radiological risk to the population near an airport was calculated, in the most extreme case analyzed, to be 2.3×10^{-2} LCF (about 1 chance in 43), assuming the accident occurred, or 3.7×10^{-8} (about 1 chance in 27 million) when the accident occurrence probability was considered. In the unlikely event of a major ship accident in a channel or at a port involving package damage and content dispersal due to a fire, the radiological risk to the population would be bounded by that assessed in the *Russian HEU Transport EA*. This risk was 0.025 LCF (about 1 chance in 40), assuming the accident were to occur, and 1.2×10^{-10} (about 1 chance in 8.3 billion), considering the probability of an accident (DOE 2004a). The quantity of material addressed in the *Russian HEU Transport EA* was larger than the maximum considered in this SA for air transport.

These risks are very small. Because no member of the public would be placed at a disproportionate risk from such an unlikely accident, no disproportionately high and adverse radiological risks would be expected to occur in low-income and minority populations.

The nonradiological impacts from normal operations that could be associated with shipment of HEU would be no larger than those associated with a shipment that did not contain HEU. Similarly, the nonradiological impacts from an accident involving a shipment of HEU would be no larger than any accident involving a shipment that did not contain HEU. An aircraft landing at any of the airports considered in this EA would be only one of numerous aircraft received annually at these ports of entry. Similarly, an ocean vessel docking at a seaport would be one of many vessels docking at a seaport Hence, no disproportionately high and adverse nonradiological risks to low-income and minority populations would result.

4.4.2 Additional Impacts from Y-12 Complex Operations

The quantity of HEU to be shipped is consistent with that previously authorized for receipt and storage at the Y-12 Complex. Therefore, there would be no additional impacts to those previously analyzed (DOE 1994, 2001).

4.5 Cumulative Impacts

The *Y-12 Site-Wide EIS* (DOE 2001) reported the estimated cumulative impacts associated with the ongoing operations of the Y-12 Complex (the ultimate destination of the HEU), the Oak Ridge Reservation, and the Watts Bar Nuclear Power Plant (including tritium production). This and other NEPA analyses also addressed transportation of nuclear material from ports of entry in the United States to the Y-12 Complex and, as part of doing so, enveloped the cumulative impacts that could result from ground transportation of the enriched uranium considered in this SA (DOE 1995b, 2001).

Incident-free transport of the HEU to United States ports of entry would not result in radiation exposures to members of the general public. Exposure to radiation would only occur to crews of aircraft carrying the HEU or to persons at the airports either unloading and loading HEU into vehicles, or a nearby noninvolved worker. The total doses for aircrew members for all shipments of HEU over a period of 10 years could be up to 1.1 person-rem (6.7×10^{-4} LCF or about 1 chance in 1,500) if all shipments were 5-kilogram (11-pound) commercial shipments, or up to 0.56 person-rem (3.4×10^{-4} LCF or about 1 chance in 2,900) if all shipments were 50-kilogram (110-pound) military shipments. For perspective, the projected collective doses to these aircrew members from cosmic radiation would be up to 58 person-rem (0.0035 LCF or about 1 chance in 290) if all shipments were 5-kilogram (11-pound) commercial shipments, or up to 16.5 person-rem (9.90×10^{-3} LCF or about 1 chance in 100) if all shipments were 50-kilogram (110-pound) commercial shipments.

It is unlikely that the same flight crew would be involved with more than a few shipments in any single year, and also unlikely that the same cargo handling crew would be involved with more than a few shipments in a single year. Shipments would enter the United States from numerous countries from around the world, and could land at several different airports, which would employ numerous cargo handlers working in different shifts for different cargo carriers. For commercial flights, if the same cargo handlers were involved in as many as 10 shipments in a year, the maximum individual dose would be 2.3 millirem, corresponding to a risk of 1.4×10^{-6} LCF (about 1 chance in 724,000), and the maximum total dose would be 0.0051 person-rem, corresponding to a risk of an LCF of 3.1×10^{-6} (about 1 chance in 320,000).

For military flights carrying HEU, several flights could arrive at a single military airport within a reasonably short period of time (i.e., all flights arriving within a year). If the same cargo handlers were involved with as many as 10 shipments in a year, the maximum dose to an individual worker would be 28 millirem, corresponding to a risk of an LCF of 1.7×10^{-5} (about 1 chance in 58,000), and the maximum total dose to all cargo handlers would be 0.062 person-rem, corresponding to a risk of an LCF of 3.7×10^{-5} (about 1 chance in 27,000).

The total dose among ground crew unloading planes and loading trucks with HEU was estimated as 0.51 person-rem (3.1×10^{-4} LCF, about 1 chance in 3,200), assuming that all shipments were to commercial airports, or 0.31 person-rem (1.9×10^{-4} LCF, about 1 chance in 5,200), assuming that all shipments were 100-kilogram (220-pound) shipments to military airbases. These doses and risks were estimated assuming average external radiation dose levels at one meter (3.3 feet) from the package surface, which were at least five times larger than those levels historically observed from HEU shipments.

Although the bulk of the shipments of HEU would be by aircraft, it is possible that a shipment of HEU could be by ocean vessel. If as many as ten shipments of large quantities of HEU (166 kilograms [365 pounds] per shipment) were to occur over the 10-year period contemplated in this SA, and the same persons were hypothetically involved with each shipment, the total doses and risks to individual crewmembers would be as follows:

- Member of a ship's crew: 20 millirem (1.2×10^{-5} LCF or about 1 chance in 83,000);
- Member of a crew transferring HEU from a vessel to a transport vehicle: 80 millirem (4.8×10^{-5} LCF or about 1 chance in 21,000);
- Member of a noninvolved dock worker or guard: 4 millirem (2.4×10^{-6} LCF or about 1 chance in 420,000).

5.0 CONCLUSION

A Supplement Analysis (SA) is a DOE document that is used to determine whether a Supplemental EIS should be prepared pursuant to 40 CFR 1502.9(c). This SA calculated the environmental impacts from shipment of up to 5,000 kilograms (11,000 pounds) of HEU (and some quantities of LEU) from foreign countries to the United States and offloading the shipments to transport vehicles. The HEU would be subsequently transported to the Y-12 Complex for temporary storage and disposition. Principal assumptions for the analysis are summarized in **Table 5–1**.

Table 5–1 Principal Assumptions for this Analysis

Total quantity of HEU over all shipments: 5,000 kilograms (11,000 pounds) in the form of U_3O_8 powder (93.5 percent U-235)
Unirradiated uranium as defined by the International Atomic Energy Agency
Unirradiated uranium meets Y-12 Complex acceptance criteria
Commercial flights – normal transport: 5 kilograms (11 pounds) in a shipment
Commercial flights – accidents: 10 kilograms (22 pounds) in a shipment
Military flights – normal transport: 50 or 100 kilograms (110 or 220 pounds, respectively) in a shipment
Military flights – accidents: 100 kilograms (220 pounds) in a shipment
Packages analyzed: TN-BGC1 and ES-2100 [a]
Commercial flights, distance to air crew: 21 meters (69 feet)
Commercial flights, number of packages: 1 TN-BGC1 or 1 ES-2100
Military flights, distance to air crew: 17 meters (56 feet)
Military flights, number of packages 16 TN-BGC1 or 8 ES-2100
Assumed dose rate on package or package array: 1 millirem per hour at 1 meter (3.3 feet)
Commercial airport 80-kilometer (50-mile) radius population increase from 2000 to 2020: 21 percent
Military airbase 80-kilometer (50-mile) radius population increase from 2000 to 2020: 46 percent
Cargo handler distance from packages (commercial or military): average of 1 to 5 meters (3.3 to 16.5 feet)
Cargo handler guard or noninvolved worker distance from packages (commercial or military): 10 meters (33 feet)
Commercial or military flight landing-stall-fire accident noninvolved worker distance: 100 meters (330 feet)
Commercial or military flight landing-stall-fire accident MEI distance: 1.6 kilometers (1 mile)

HEU = highly enriched uranium, MEI = maximally exposed individual.
[a] The 5X22 package is encompassed by this assumption.

The environmental impacts determined in this SA from HEU (and some quantities of LEU) shipment are consistent with, if not smaller than, those for other environmental assessments considering similar shipments of unirradiated nuclear reactor fuel to the United States. It was determined from all these assessments that such shipments would not constitute major federal actions significantly impacting the quality of the environment. This is the case for any single shipment of HEU under both incident-free transport and accident conditions.

Individual Air Shipments

Doses and risks from individual air shipments of enriched uranium are summarized in **Table 5–2**. Using the assumed external radiation dose rate from HEU packages, the largest dose and risk to an individual were estimated to be 2.8 millirem and 1.7×10^{-6} LCF (about 1 chance in 595,000) to a cargo handler unloading 100 kilograms (220 pounds) of HEU at a military airbase. Based on experience with actual HEU shipments, this dose and risk would actually be closer to 0.56 millirem (3.4×10^{-7} LCF or about 1 chance in 2.97 million). However, a wide range of international shipments of unirradiated uranium may occur over the next 10 years, and these shipments may differ from those assumed for the analysis in this SA. HEU shipments may be larger than those assumed for the SA; the surface dose rates of HEU containers may be larger than those historically experienced; different aircraft could be used (or operational procedures may change) that would reduce the average distances assumed between air and ground crew and packages of HEU. Therefore, Appendix A provides a method to estimate radiological impacts from actual air shipments for both incident-free transport and accident conditions.[30]

Table 5–2 Impacts from Individual Air Shipments of Enriched Uranium

Dose Receptor (scenario)	*Radiation Dose (person-rem)*	*Risk (LCF)* [a]	*Air Flight Cosmic Radiation Dose and Risk (person-rem/LCF)*
Single Military Air Shipment of Unirradiated Enriched Uranium			
Aircrew member (normal operations), 100 kilograms	5.1×10^{-4}	3.1×10^{-7}	1.5×10^{-2} / 9×10^{-6}
Ground cargo handler (normal operations), 100 kilograms	2.8×10^{-3}	1.7×10^{-6}	Not applicable
Non-involved worker (accident), 100 kilograms	0.113	1.08×10^{-10}	Not applicable
MEI (accident), 100 kilograms	7.04×10^{-4}	6.75×10^{-13}	Not applicable
50-mile population (accident), 100 kilograms	38.5	3.70×10^{-8}	Not applicable
Single Commercial Air Transport of Unirradiated Enriched Uranium			
Aircrew member (normal operations), 5 kilograms	2.8×10^{-4}	1.7×10^{-7}	1.4×10^{-2} / 8.64×10^{-6}
Ground cargo handler (normal operations), 5 kilograms	2.3×10^{-4}	1.4×10^{-7}	Not applicable
Non-involved worker (accident), 10 kilograms	0.0113	1.90×10^{-12}	Not applicable
MEI (accident), 10 kilograms	7.04×10^{-5}	1.18×10^{-14}	Not applicable
50-mile population (accident), 10 kilograms	9.01	1.51×10^{-9}	Not applicable

LCF = latent cancer fatality, MEI = maximally exposed individual.
[a] Normal operations risk uses a probability of 1, whereas military air transport accident risk includes a probability of 1.6×10^{-6} per operation and commercial air transport accident risk includes a probability of 2.8×10^{-7} per operation.
Note: To convert kilograms to pounds, multiply by 2.2.

Multiple Air Shipments

For multiple shipments of HEU, no member of either a commercial or a military flight crew would receive a radiation dose from the HEU in excess of the DOE limit of 100 millirem in a year to members of the public. This conclusion is predicated on the assumption of continued radiation protection practices, including the existing practice for shipping radioactive materials by aircraft and the shipment of HEU emitting low levels of external radiation. Radiation doses from transporting the HEU would be far smaller than those from cosmic radiation. For radiation doses from all sources (transported radioactive material plus cosmic radiation), the FAA recommends occupational radiation dose limits of up to 5 rem in a single year, or 2 rem as averaged over 5 years (FAA 1990). These limits are the same as those adopted by the NRC and DOE for occupational protection of radiation workers. Military occupational radiation protection standards correspond to DOE and NRC requirements and FAA recommendations.

If the same members of a ground crew handling the HEU packages were involved with as many as 10 shipments in a year, the maximum annual doses would still be smaller than the DOE 100 millirem radiation dose limit for members of the public. These maximum annual doses would also be well below

[30] Although impacts from accident conditions depend on the kinds and quantities of the shipped radionuclides, impacts from incident-free transportation do not. For incident-free transport, radiological doses and risks to aircrew, cargo handlers, or other individuals depend on the external radiation levels at package surfaces rather than the particular mix of radionuclides inside the package that cause the external radiation. For accidents, provided that the radioactive material shipped with the HEU is only unirradiated uranium (of any enrichment), Appendix A can be used to compare the postulated impacts from an actual air shipment of uranium with those calculated for this SA.

recommended limits for occupational radiation dose. Based on past experience with radiation levels for HEU shipments, these maximum annual doses are conservative. Assuming radiation exposure levels consistent with historical DOE experience with shipments of HEU, the total radiation dose to an individual member of a ground crew would be smaller than 100 millirem from all projected shipments over 10 years.

Radiation doses that may be experienced by members of air and ground crews can be maintained to ALARA levels by NNSA personnel continuing to:

- Monitor radiation levels and doses that may result from large shipments of HEU;
- Track radiation dose levels on packages of received HEU to ascertain any increasing trends; and
- Remain cognizant of the types of aircraft that may be used for HEU shipments, and standard shipment and cargo handling practices, to ascertain whether major changes should be made regarding assumptions about average distances between HEU packages and flight and ground crews.

Ocean Shipments

Some shipments may be made by ocean vessel, likely as co-shipments with foreign reactor spent nuclear fuel. Based on the assessments in previous NEPA analyses (DOE 1996a, 2004a) and in this SA, it is unlikely that an occasional shipment of HEU by ocean vessel would cause any individual to exceed DOE's annual 100-millirem radiation dose limit for members of the public.

Y-12 Complex Operations

The quantities of HEU to be stored are within the limits previously authorized in the *Y-12 Site-Wide EIS* (DOE 2001) and its associated EA (DOE 1995b). Therefore, there would be no impacts on the environment in the vicinity of the Y-12 Complex or on Y-12 Complex operations that have not been previously analyzed.

Overall Conclusion

NNSA has determined that the continued acceptance of enriched uranium at the Y-12 Complex in quantities up to 5,000 kilograms (11,000 pounds) from foreign countries for temporary storage and disposition would not constitute significant new circumstances or information relevant to environmental concerns. This SA concludes that the Proposed Action is not a substantial change to the proposal analyzed in the *Y-12 Site-Wide EIS* and other NEPA documents. Therefore, no supplement to the *Y-12 Site-Wide EIS* needs to be prepared and no additional transportation analyses are expected to be required for future shipments during the next 10 years.

6.0 DETERMINATION

In compliance with DOE NEPA regulations, 10 CFR Part 1021, Section 1021.314(c). DOE/NNSA has examined the circumstances relevant to the Proposed Action to continue transport of HEU (and some LEU) between locations in foreign countries and the United States, where enriched uranium transported to the United States would continue to be temporarily stored at the Y-12 Complex pending its further disposition. The examination was performed to determine whether the Proposed Action would result in a substantive change to the environmental impacts reported in the *Y-12 Complex Site-Wide EIS* (DOE 2001) and related NEPA documents. Implementation of the Proposed Action would be expected to result in environmental impacts that are either within the range of the environmental impacts analyzed in the *Y-12 Complex Site-Wide EIS* or present no substantive change to those impacts. The Proposed Action would not constitute a substantial change in action relevant to environmental concerns. There are no significant new circumstances or information relevant to environmental concerns related to the Proposed Action or its impacts within the meaning of 40 CFR 1502.9(C) and 10 CFR 1021.314. Therefore, neither a supplement to the *Y-12 Complex Site-Wide EIS* nor a new EIS is needed.

Issued in Oak Ridge, Tennessee, this 25th day of August, 2006.

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7.0 REFERENCES

Aerospace Technology, 2006, Kamov KA-226, Sergei Light Multipurpose Helicopter, Russia, Available at http://www.aerospace-technology.com/projects/ka226/.

Air Force (U.S. Air Force), 2006, Air Force Link Fact Sheets: C-141 Starlifter, C-17 Geobemaster III, C-5 Galaxy, May, Available at http://www.af.mil/factsheets/.

ARI (Air Routing International, L.P.), 2006, Time/Distance Calculator, Available at http://www.airrouting.com/content/tdcalc.html.

Boeing (The Boeing Company), 2006a, Boeing Commercial Airplanes, 747 Fun Facts, Available at http://www.boeing.com/commercial/747family/pf/pf_facts.html.

Boeing (The Boeing Company), 2006b, Boeing Commercial Airplanes, 767 Fun Facts, Available at http://www.boeing.com/commercial/767family/pf/pf.facts.html.

Boeing (The Boeing Company), 2006c, Boeing Commercial Airplanes, Technical Characteristics, Boeing 777 Freighter, available at http://www.boeing.com/commercial/777family/pf/pf_freighter_product.html.

Campbell, Mark, 2006a, Personal communication (E-mail) from M. Campbell, Nuclear Transportation Manager, Edlow International Company, to G. Roles, Science Applications International Corporation, Subject: Parameters for Long Distance Flights, May 5.

Campbell, Mark, 2006b, Personal communication (E-mail) from M. Campbell, Nuclear Transportation Manager, Edlow International Company, to G. Roles, Science Applications International Corporation, Subject: Crew Sizes for Average Flight Speeds and Crew Number for Long Distance Flight Aircraft, May 17.

Campbell, Mark, 2006c, Personal communication (E-mail) from M. Campbell, Nuclear Transportation Manager, Edlow International Company, to G. Roles, Science Applications International Corporation, Subject: Flight Duty Hours, May 19.

Census (U.S. Census Bureau), 2006, State and County QuickFacts, Queens County, New York, Available at http://quickfacts.census.gov/qfd/states/36/36081.html, July 21.

DOC (U.S. Department of Commerce), 2002, UA Census 2000 TIGER/Line® Files Technical Documentation, Geography Division, U.S. Census Bureau, Washington, DC, Available at http://www.census.gov/geo/www/tiger/tigerua/ua2ktgr.pdf, April.

DOC (U.S. Department of Commerce), 2005, Technical Documentation: Census 2000 Summary File 1, SF1/13(RV), Economics and Statistics Administration, U.S. Census Bureau, Washington, DC, Available at http://www.census.gov/prod/cen2000/doc/sf1.pdf, March.

DOD (U.S. Department of Defense), 1996, Department of Defense Instruction, *Occupational Radiation Protection Program*, Number 6055.8, Change 1, May 6.

DOE (U.S. Department of Energy), 1994, *Environmental Assessment for the Proposed Interim Storage at the Y-12 Plant Oak Ridge, Tennessee of Highly Enriched Uranium Acquired from Kazakhstan by the United States* [redacted], DOE/EA-1006, October.

DOE (U.S. Department of Energy), 1995a, *Finding of No Significant Impact: Interim Storage of Highly Enriched Uranium at the Y-12 Plant, Oak Ridge, Tennessee, Acquired from Kazakhstan by the United States*, Office of Nonproliferation and National Security, Washington, DC, March 6.

DOE (U.S. Department of Energy), 1995b, *Environmental Assessment for the Proposed Interim Storage of Enriched Uranium Above the Maximum Historical Storage Level at the Y-12 Plant, Oak Ridge, Tennessee*, DOE/EA-0929, Washington, DC, May.

DOE (U.S. Department of Energy), 1996a, *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel*, DOE/EIS-218F, Assistant Secretary for Environmental Management, Washington, DC, February.

DOE (U.S. Department of Energy), 1996b, *Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement*, DOE/EIS-0229, Office of Fissile Materials Disposition, Washington, DC, December.

DOE (U.S. Department of Energy), 1998, *Supplemental Analysis of Acceptance of Foreign Research Reactor Spent Nuclear Fuel Under Scenarios not Specifically Mentioned in the EIS*, DOE/EIS-0218-SA-2, Washington, DC, August 19.

DOE (U.S. Department of Energy), 2001, *Final Site-Wide Environmental Impact Statement for the Y-12 National Security Complex*, DOE/EIS-0309, National Nuclear Security Administration, Oak Ridge Operations Office, Oak Ridge, Tennessee, September.

DOE (U.S. Department of Energy), 2003, "ES-2100 Container Description and Graphic," National Nuclear Security Administration, Offsite Transportation Authorizations/Certificates, Available at www.doeal.gov/nnsaota/ContainerID/ES-2100.htm, February 4.

DOE (U.S. Department of Energy), 2004a, *Environmental Assessment for the Transportation of Highly Enriched Uranium from the Russian Federation to the Y-12 National Security Complex and Finding of No Significant Impact*, DOE/EA-1471, National Nuclear Security Administration, Russian HEU Programs, Washington, DC, January.

DOE (U.S. Department of Energy), 2004b, *Foreign Research Reactor Spent Nuclear Fuel Acceptance Program*, Savannah River Operations Office, January 21.

DOE (U.S. Department of Energy), 2004c, *Supplement Analysis for the Foreign Research Reactor Spent Nuclear Fuel Acceptance Program*, DOE/EIS-0218-SA-3, National Nuclear Security Administration, Washington, DC, November.

DOE (U.S. Department of Energy), 2005a, *Environmental Assessment for the Transportation of Unirradiated Uranium in Research Reactor Fuel from Argentina, Belgium, Japan, and the Republic of Korea to the Y-12 National Security Complex* [Official Use Only], DOE/EA-1529, National Nuclear Security Administration, Washington, DC, June.

DOE (U.S. Department of Energy), 2005b, *Finding of No Significant Impact for the Environmental Assessment for the Transportation of Unirradiated Uranium in Research Reactor Fuel from Argentina, Belgium, Japan, and the Republic of Korea to the Y-12 National Security Complex* [Official Use Only], National Nuclear Security Administration, Aiken, South Carolina, July 6.

DOE (U.S. Department of Energy), 2006a, *DOE Standard, Accident Analysis for Aircraft Crash Into Hazardous Facilities*, DOE-STD-3014-2006, Washington, DC, May.

DOE (U.S. Department of Energy), 2006b, Personal communication (E-mail) from L. Ballard, U.S. Department of Energy, Y-12, to G. Roles, Science Applications International Corporation, Subject: Radiation Protection Procedures, May 22.

DOE (U.S. Department of Energy), 2006c, Personal communication (E-mail) from T. Andes, U.S. Department of Energy, Y-12, to S. Mirsky, Science Applications International Corporation, Subject: GTRI SA Transportation Support Data, June 19.

DOE (U.S. Department of Energy), 2006d, Personal communication (E-mail) from T. Andes, U.S. Department of Energy, Y-12, to S. Mirsky, Science Applications International Corporation, Subject: GTRI SA Transportation Support Data, Additional Data Point, June 20.

DOT (U.S. Department of Transportation), 1998, *Hazardous Materials Shipments*, Office of Hazardous Materials Safety, Washington, DC, October.

DOT (U.S. Department of Transportation), 2006, Competent Authority Certification for a Type B(U)F Fissile Radioactive Materials Package Design Certificate USA/0492/B(U)F-96, Revision 8, Revalidation of French Competent Authority Certificate F/313/B(U)F-96, Pipeline and Hazardous Materials Safety Administration, Washington, DC, April 7.

EPA (U.S. Environmental Protection Agency), 1988, *Limiting Values of Radionuclide Intake And Air Concentration and Dose Conversion Factors For Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, EPA 520/1-88-020, Office of Radiation Programs, Washington, DC, September.

FAA (Federal Aviation Administration), 1990, *Radiation Exposure of Air Carrier Crewmembers*, Advisory Circular No. 120-52, U.S. Department of Transportation, March 5.

FAA (Federal Aviation Administration), 2003, *What Aircrews Should Know About Their Occupational Exposure to Ionizing Radiation*, DOT/FAA/AM-03/16, Office of Aerospace Medicine, U.S. Department of Transportation, Washington, DC, October.

Federation of American Scientists, 1999, Airlift Cargo Aircraft, Military Analysis Network, Available at http://www.fas.org/man/dod-101//sys/ac/lift_comp, November 19.

GAO (United States General Accounting Office), 2003, *Aviation Safety, Undeclared Air Shipments of Dangerous Goods and DOT's Enforcement Approach*, GAO-03-22, Washington, DC, January.

IAEA (International Atomic Energy Agency), 2002, *IAEA Safeguards Glossary*, 2001 Edition, International Nuclear Verification Series No. 3, Vienna, Austria, June.

IAEA (International Atomic Energy Agency), 2005, *Regulations for the Safe Transport of Radioactive Material, 2005 Edition*, Safety Requirements No. TS-R-1, Vienna, Austria, August.

Jane's Civil Aerospace News, 2000a, Jane's All The World's Aircraft: AIRBUS A320, Available at http://www.janes.com/aerospace/civil/news/jawa/jawa000824_n_2.shtml, August 24.

Jane's Civil Aerospace News, 2000b, The BOEING COMPANY, BOEING 747-400, Jane's All the World's Aircraft, Available at http://www.janes.com/aerospace/civil/news/jawa/jawa001101_1_ n.shtml, October 31.

LAWA (Los Angeles World Airports), 2006a, LAX - Just the Facts, Available at http://www.lawa.org/lax/JustTheFact.cfm, July.

LAWA (Los Angeles World Airports), 2006b, LAX - General Description, Available at http://www.lawa.org/lax/GeneralDescription.cfm, July

NEI (Nuclear Energy Institute), 2005, Fact Sheet, Transporting Radioactive Materials, Available at http://www.nei.org/doc.asp?catnum=3&catid=66&docid=&format=print, Washington, DC, October.

NOAA (National Oceanic and Atmospheric Administration), 2000, Notes on the Natural Radiation Hazard at Aircraft Altitudes, Available at http://www.sec.noaa.gov/info/RadHaz.html, March.

NRC (U.S. Nuclear Regulatory Commission), 1998, Code Manual for MACCS2: Volume 1, User's Guide, NUREG/CR-6613, SAND97-0594, May.

PANYNJ (Port Authority of New York and New Jersey), 2006a, John F. Kennedy International Airport Fact Sheet, Available at http://www.panynj.gov/aviation/jhisfram.htm.

PANYNJ (Port Authority of New York and New Jersey), 2006b, Newark Liberty Airport Fact Sheet, Available at http://www.panynj.gov/CommutingTravel/airports/html/ewr_facts.html.

PANYNJ (Port Authority of New York and New Jersey), 2006c, 2004 Airport Traffic Report.

SNL (Sandia National Laboratories), 2003, *RADTRAN 5 User Guide*, SAND2003-2354, Albuquerque, New Mexico, and Livermore, California, July.

Tabmag (Tabmag Publishing Ltd.), 2006, Airbus – A310, Freighters Online, Available at http://www.freightersonline.com/plane.aspx?a=7.

UIC (Uranium Information Centre Ltd), 2005, *Transport of Radioactive Materials*, Nuclear Issues Briefing Paper No. 51, Available at http://www.uic.com.au/nip51.htm, Melbourne, Australia, September.

Wikipedia (Wikimedia Foundation Inc), 2006a, Newark, New Jersey, Available at http://en.wikipedia.org/wiki/Newark,_New_Jersey.

Wikipedia (Wikimedia Foundation Inc), 2006b, Los Angeles, California, Available at http://en.wikipedia.org/wiki/Los_Angeles,_California.

WNTI (World Nuclear Transport Institute), 2006, Facts and Figures, Available at http://www.wnti.co.uk/factsandfigures.html.

Appendix A Generic Method for Comparison of Shipments to Analysis Coverage

Appendix A Generic Method for Comparison of Shipments to Analysis Coverage

This Supplement Analysis (SA) presents an assessment of the impacts of transportation of enriched uranium (highly-enriched uranium and low enriched uranium [HEU and LEU]) from foreign nations to the United States. For air transport, the impact analyses are presented in this SA based on hypothetical shipments that provide an upper bound for impacts of any actual shipment. For ocean transport, impact analyses are included in earlier National Environmental Policy Act (NEPA) analyses (and referenced herein), and the impacts associated with ocean transport of up to 166 kilograms (365 pounds) of HEU per vessel would be bounded by those in the earlier analyses.

A wide range of international air shipments of unirradiated HEU to the Y-12 Complex may occur over the next ten years. Recognizing that actual shipments of HEU by commercial or military air cargo may differ from those assumed for the analysis in the main body of this SA, this appendix supplies information that can be used to estimate radiological impacts from actual shipments. The discussion provides guidance for evaluating actual air shipments (for incident-free transport and for accident conditions). The analyst would need to know the specific quantity, content and configuration of the unirradiated HEU or LEU that is intended for the shipment (note that the cargo must meet the IAEA-TS-R1 definition of unirradiated nuclear fuel and the Y-12 Complex Acceptance Criteria); whether the shipment will be by military or commercial aircraft; and specific information regarding routes, flight times, and crews.

Determining Impacts from Incident-Free Air Transport

The radiological dose to the persons on the cargo plane (aircrew) would be proportional to the package surface dose rate, the crew-view package characteristic dimensions (i.e., the surface of the package array that faces the crew), the crew-to-package distance, and the time between boarding the aircraft and exiting at a final destination. The radiological dose to ground cargo handlers would be proportional to the package surface dose rate, the package length, the crew-to-package distance, and the time required to unload the HEU packages from the aircraft and load them into the ground transport vehicles.

Doses to aircrew members and individual ground cargo handlers were assessed using two sets of packages (TN-BGC1 and ES-2100) that are currently certified. **Table A–1** provides the important characteristics of these packages and the various values used in the analysis. Typical package loading activities are illustrated in **Figure A–1**.

Doses were estimated using the RADTRAN 5 computer program (SNL 2003). This program uses the following expression (SNL 2003) to calculate dose rate to an individual at a fixed distance from the package in Equation A-1.

$$DR(r) = DR_g(r) + DR_n(r) \qquad \text{(A-1)}$$

Where: $DR_g(r)$ and $DR_n(r)$ are dose rates from gamma and neutron radiation at a distance r from the package. Assuming that the dose rate is from gamma radiation only,[31] the expression $DR_g(r)$ is given in terms of transport index, (the dose rate at 1 meter [3.3 feet] from the package), and the package shape factor in Equation A-2 (SNL 2003).

[31] *Neutron dose rate from spontaneous fission and alpha radiation emission is much lower than the gamma dose rate for unirradiated enriched uranium.*

Table A–1 Important Parameters and Values used in the Analysis

Packages	*Characteristic*	*Distance to Crew*	*Distance to Cargo Handling Individual at Airports and Airbases*
TN-BGC1			
Crew-view Commercial [a] Military [b]	 1.90 meters 2.16 meters	 21 meters 17 meters	Not applicable
Package length Commercial [a] Military [b]	 0.60 meters 4.8 meters	Not applicable	10 meters for the guards and between 1 to 5 meters for workers
ES-2100			
Crew-view Commercial [a] Military [c]	 1.10 meters 1.50 meters	 21 meters 17 meters	Not applicable
Package length Commercial [a] Military [c]	 0.60 meters 2.40 meters	Not applicable	10 meters for the guards and between 1 to 5 meters for workers
Dose at 1 meter	1 millirem per hour	Not applicable	Not applicable

[a] This characteristic length is for one package.
[b] This characteristic length is for a 2 × 8 package array, with the crew exposed to the doses from surfaces of two packages.
[c] This characteristic length is for a 2 × 4 package array, with the crew exposed to the doses from surfaces of two packages.
Note: To convert from meters to feet, multiply by 3.3.

$$DR_g\ (r) = DR\ (1)\ x\ k\ /r^{\ n} \tag{A-2}$$

Where:

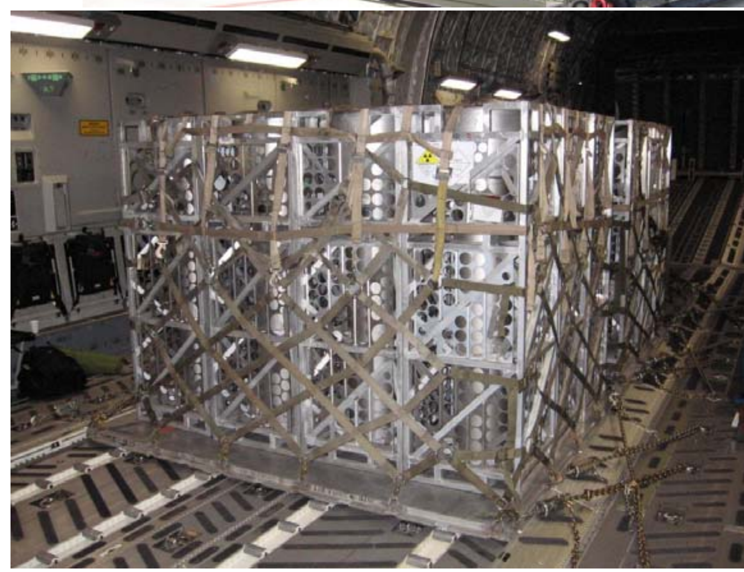
- DR (1) = gamma dose rate at 1 meter (3.3 feet) from the package
- k = package shape factor = $(1+0.5\ D_e)^{\ n}$
- D_e = effective package dimension, related to the characteristic package dimension (such as crew view, or package length).
- n = has a value of 1 for distances less than or equal $2D_e$ (a line source), and 2 (point source) for other distances.

The effective package dimension is calculated below in Equation A-3 (SNL 2003):

$$D_e = \left| \begin{array}{l} D, if\ \ D \le 4 \\ 2(1+0.5D)^{0.75} - 0.55, if\ \ 9 > D > 4 \end{array} \right. \tag{A-3}$$

Where: D is the package characteristic dimension (in meters) and should be less than 9 meters.

For the TN-BGC1 package array, the effective dimension (D_e) for crew exposure and the package length would be 2.16 and 4.46 meters, respectively. Note that adjustments were made only to the package length, since it is longer than 4 meters. Also note that, for dose rate calculation, the parameter n is equal to 1 for crew distances of up to 4.4 meters and for worker distances of up to 9 meters. For distances beyond these values, parameter n is equal to 2.



These photographs show the handling and arrangement of TN-BGC1 packages into an array and positioning them within a military aircraft. These pictures show two 3x4 arrays and one 2x4 array of packages, all secured upright on a pallet before they are moved into the cargo compartment and secured to the cargo deck. During unloading a reverse process would occur before these packages are secured in a safe secure trailer for transport to the Y-12 Complex.

Figure A–1 Typical Loading Activities

An example of the application of this methodology to the TN-BGC1 package follows. The dimensions of the TN-BGC1 and ES-2100 packages are presented in Figures 2-1 and 2-2. For the TN-BGC1 packages, the package configuration is a 2 x 8, or 2 packages wide by 8 packages long. Each package has a dimension of about 1.8 meters (about 6 feet) high and 0.60 meter (about 2 feet) wide. Therefore, a crew view of 2 packages would have a characteristic dimension (diagonal) length of 2.16 meters (about 7 feet). The package array length is about 4.8 meters (about 16 feet), (i.e., 8 packages of 0.60 meters width each). Since the package length is longer than 4 meters, the effective dimension using Equation A-3 would be 4.46 meters. The crew view would not require any adjustment, since it is less than 4 meters, see Equation A-3.

Using Equation A-3, and the length of D=4.8 meters, the effective dimension is calculated below,

$$\begin{aligned} D_e &= 2 \text{ x } (1 + 0.5 \text{ D})^{0.75} - 0.55 = 2\ (1 + 0.5 * 4.8)^{0.75} - 0.55 \\ &= 2\ (1+ 2.4)^{0.75} - 0.55 = 2 \text{ x } (3.4)^{0.75} - 0.55 = 2 \text{ x } 2.504 - 0.55 \\ &= 5.008 - 0.55 = 4.458, \text{ or } 4.46 \end{aligned}$$

Since it is possible that assumed distances and dose rates could be different in future transports, parametric dose rate calculations were performed for the TN-BGC1 package array. This package array would result in larger doses to both an aircrew member and to an individual ground cargo handler at an airport. **Figures A–2 and A–3** provide the normalized dose to an aircrew member and an individual cargo loader at various distances from the package array used in a military cargo shipment. These figures could be used to calculate a new dose rate for an aircrew member or individual cargo handler, given the results provided in this analysis. For example, if an aircrew member were to be exposed to the package at a minimum distance of 10 meters, instead of 17 meters, with a package surface dose rate of 0.5 millirem per hour at one meter, rather than one millirem per hour at one meter, then the new dose can be calculated using Equation A-4:

$$D_N = D_O \cdot \left(\frac{DR_N}{DR_O} \right) \cdot \left(\frac{ND_N}{ND_O} \right) \tag{A-4}$$

Where:

- D_N = New dose
- D_O = Old dose rate (calculated earlier as 1.51×10^{-5} rem/hour)
- DR_N = New dose rate at 1 meter (3.3 feet)
- DR_O = Old dose rate at 1 meter (1 millirem/hour)
- ND_N = New normalized dose rate at new distance
- ND_O = Old normalized dose rate at old distance (at 17 meters or 56.1 feet is 0.0072 rem/hour)

Values for D_O, and ND_O are presented in **Table A–2**.

Table A–2 Values of D_o and ND_o

Mode	*Receptor*	*D_o (rem/hour)*	*ND_o (rem/hour)*	*ND_o Distance (meters)*
Military	Aircrew member	1.51×10^{-5}	7.20×10^{-3}	17
Military	Individual cargo handler (e.g., guard or NIW)	1.0×10^{-4}	3.23×10^{-2}	10
Commercial	Aircrew member	8.46×10^{-6}	4.42×10^{-3}	21
Commercial	Individual cargo handler (e.g., guard or NIW)	1.7×10^{-5}	1.32×10^{-2}	10

D_o = old dose rate; ND_o = old normalized dose rate; NIW = noninvolved worker.
Note: To convert meters to feet, multiply by 3.3.

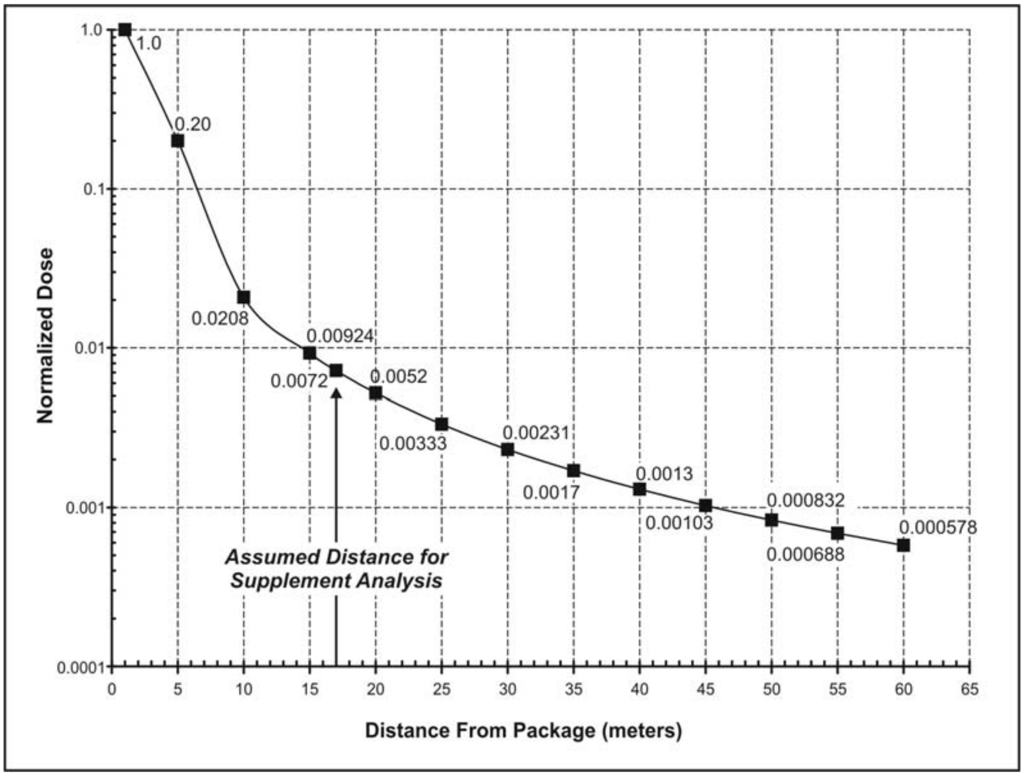


Figure A–2 Normalized Military Aircrew Member Dose Versus Distance

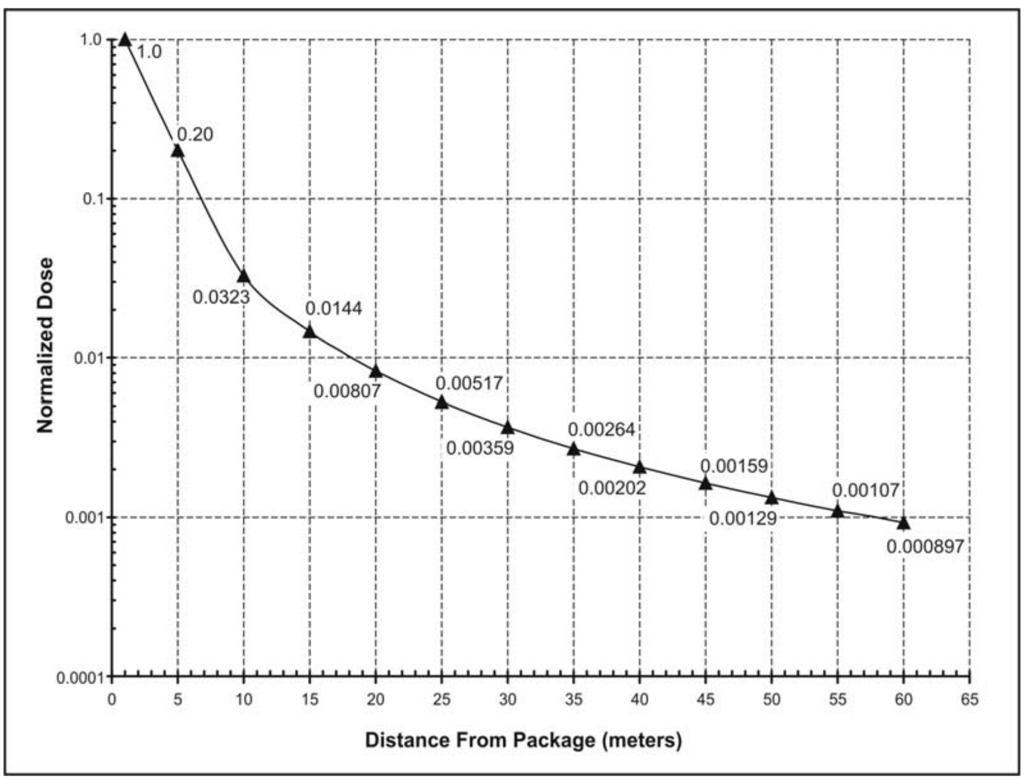


Figure A–3 Normalized Individual Dose Versus Distance at a Military Base

From Figure A–2, the normalized dose at 10 meters from the package is 0.0208; the new dose at 10 meters from the package would be:

$$D_N = (1.51 \times 10^{-5}) * (0.50/1.0) * (0.0208/0.0072) = 2.18 \times 10^{-5} \text{ rem/hour}$$

Figures A–4 and A–5 provide the normalized dose to an aircrew member and an individual ground cargo handler at various distances from a TN-BGC1 package used for commercial cargo shipment. These figures can also be used to calculate new dose at distances desired using Equation A-4. Note that the dose rate previously determined for cargo handlers was based on the assumption that the worker would be located at a distance from the package ranging between 1 and 5 meters. Equation A-4 and Table A–2 can be used to estimate dose rates for any fixed distance between 1 and 65 meters. This equation also indicates that dose is proportional to the 1 meter (3.3 foot) dose rate. Therefore, if the new dose rate is smaller, the worker dose will also be proportionally lower.

The dose received by the aircrew member over the entire flight is the product of the calculated dose rate for the new situation with the total number of hours required for the shipment. The total hours are the sum of the total time spent in flight with the total time spent on the ground. For shorter flights, where a non-stop shipment can be assumed, there would be a short period between loading and takeoff and between landing and arrival at the cargo handling area. A half-hour at either end of the flight was assumed for the SA. For longer flights, there may be a need to stop and refuel or perform other activities, such as crew change.

The dose to a cargo handler was determined assuming a cargo handling time of 2 hours at the military airbase, and 1 hour at the commercial airport.

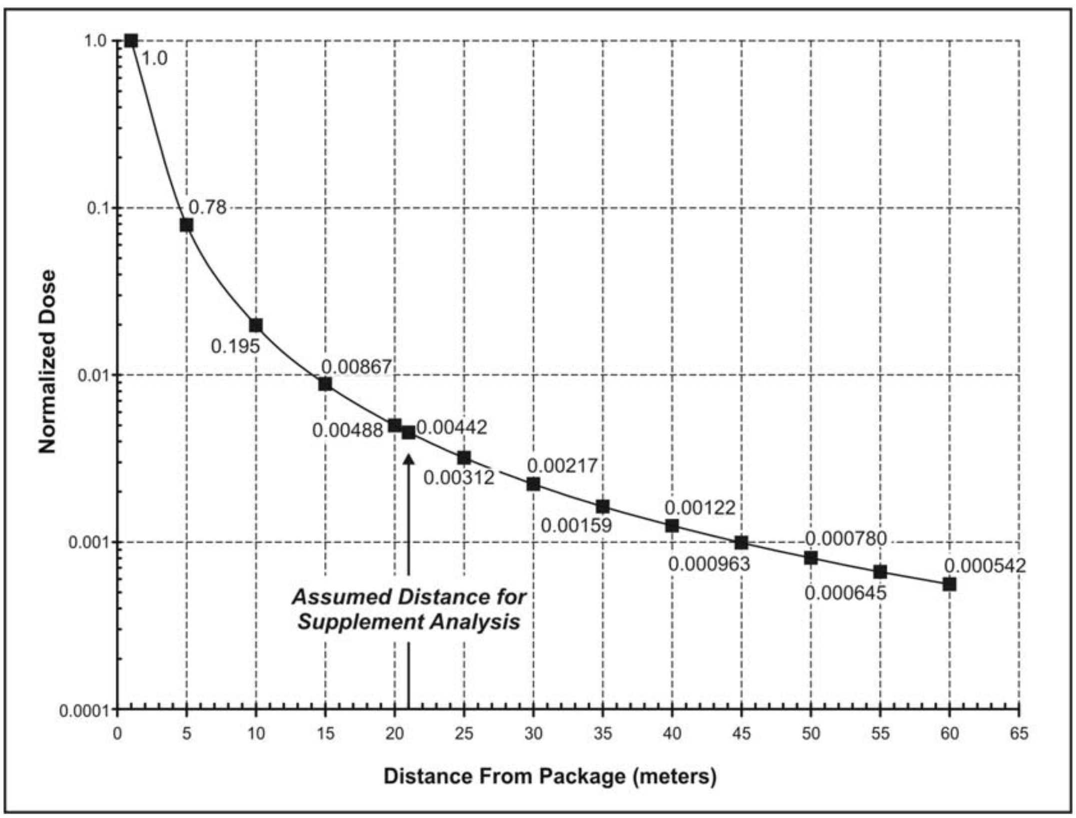


Figure A–4 Normalized Commercial Crewmember Dose Versus Distance

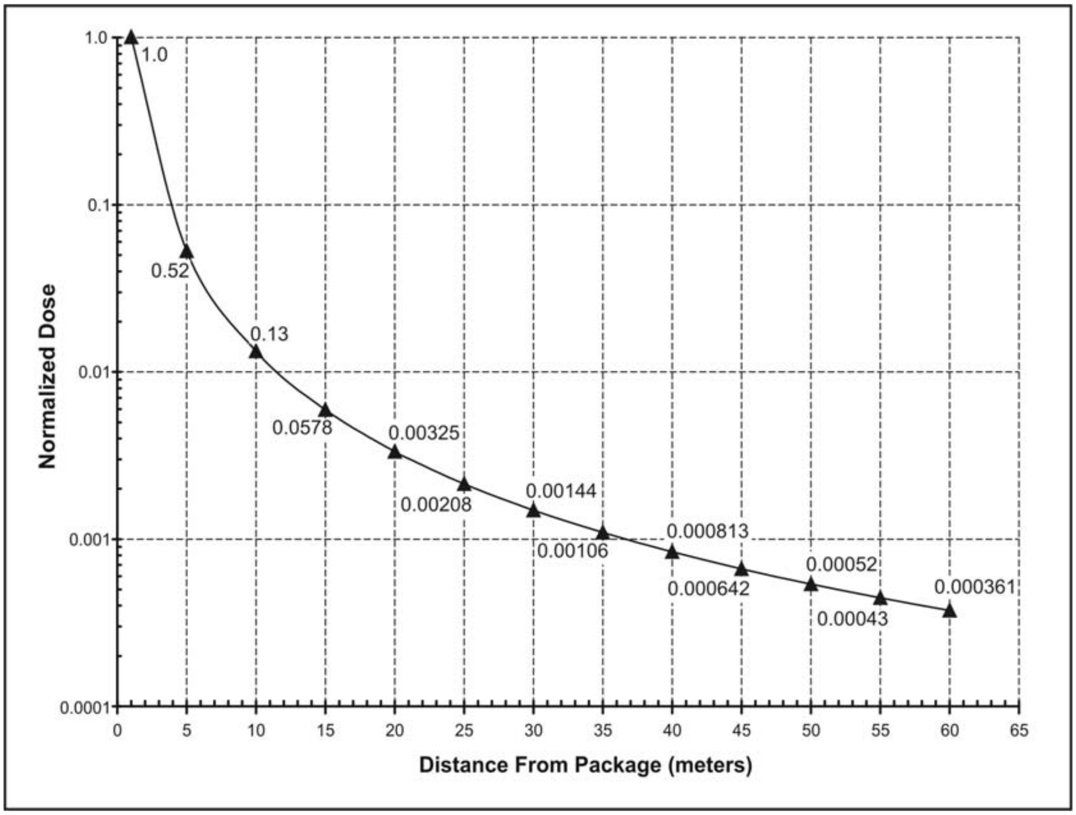


Figure A–5 Normalized Individual Dose Versus Distance at a Commercial Airport

Determining Impacts from Air Transport Accidents

To accommodate foreseeable shipments, a generic methodology was developed to calculate the NIW, MEI, and population dose for accident conditions. Considering the types of impacts assessed in this SA, the analyst would apply the following steps to the specific shipment information in order to calculate dose to the MEI, NIW, and 80-kilometer (50-mile) population.

1. Enter individual air shipment payload of uranium-235 and uranium-238 mass (in grams).[a]
2. Multiply total uranium-238 mass (in grams)[a] by 7.6E-3[b] to calculate the mass (in grams)[a] of uranium-234.
3. Multiply uranium-235 mass (in grams)[a] by 5E-3[c] to calculate uranium-236 mass (in grams).[a]
4. Convert uranium isotope mass to activity in curies[d] by multiplying uranium-235 mass (in grams)[a] by 2.16E-6; uranium-234 mass (in grams)[a] by 6.4E-3; uranium-236 mass (in grams)[a] by 6.48E-5; and uranium-238 mass (in grams)[a] by 3.34E-7.
5. Add all individual uranium isotope activities to a sum of all uranium activity (U).

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[a] *To convert pounds to grams, multiply by 454.*
[b] *Based on natural abundance of uranium-234 in uranium-235 (i.e., 0.0055% / 0.72%)*
[c] *Based on IAEA definition of unirradiated uranium.*
[d] *Based on individual uranium isotope specific activity in curies per gram.*

6. Multiply uranium-235 mass by 5.41E-8 [c] to calculate plutonium (Pu) activity in curies.
7. Multiply uranium-235 mass by 2.43E-4 [c] to calculate fission product (FP) activity in curies.
8. Calculate noninvolved worker (NIW), maximally exposed individual (MEI), and 50-mile radius population (POP) doses with the following equations which were developed based on MACCS2 computer code calculations with unit values of individual radioisotopes and the 2020 population increase estimates of 21 percent for a commercial airport and 46 percent for a military airbase.

NIW (rem) = 0.028 U + 0.0687 Pu + 7.31E-5 FP
MEI (rem) = 1.74E-4 U + 4.28E-4 Pu + 2.41E-7 FP
For a Military Airport up to the year 2020
POP (person-rem) = 1.46 (653 U + 1,600 Pu + 0.903 FP)
For a Commercial/Civil Airport up to the year 2020
POP (person-rem) = 1.21 (1,850 U + 4,530 Pu + 2.55 FP)

Where: U is the total uranium activity in curies; Pu is the total plutonium activity in curies; and FP is the total fission product activity in curies. NIW = noninvolved worker; MEI = maximally exposed individual; and POP = 50 miles radius population dose.

The calculated doses should be compared to the bounding values in this SA of:

Military Aircraft

NIW dose of 1.13×10^{-2} rem; MEI dose of 7.04×10^{-4} rem; and Population dose of 38.5 person-rem

Commercial Aircraft

NIW dose of 1.13×10^{-1} rem; MEI dose of 7.04×10^{-5} rem; and Population dose of 9.01 person-rem

This methodology is based on the following assumptions: (1) enriched uranium, either HEU or LEU, is being transported; and (2) the enriched uranium meets the IAEA-TS-R1 definition of unirradiated uranium (and Y-12 Acceptance Criteria). Furthermore, the methodology is based on conservative assumptions regarding the physical form (uranium oxide powder) and atmospheric dispersion of the enriched uranium (no emergency response). Moreover, the radiological consequences in the form of 50-mile (80 kilometer) radius population radiation doses include a factor of 1.46 for military airports and 1.21 for commercial airports to account for increased population between the years 2000 and 2020. Previous HEU shipments to the Y-12 complex have involved a number of different physical and chemical forms. The results of this methodology will bound other chemical forms such as uranium dioxide, uranium metal, uranium-aluminum alloy, uranium carbide, uranium nitride, and uranium zirconium hydride. Similarly, the results of this methodology will bound other physical forms such as pellets, billets, plates, rods, scrap, and fuel elements.

Determining Impacts from Ocean Transport

Accident impacts associated with the ocean transport of HEU or LEU are bounded by a postulated accident in a port, which was analyzed in the *Russian HEU Transport EA* and described in Section 4.3.4 of this SA. For the ocean transport of up to 166 kilograms (365 pounds) of HEU or LEU, the accident and normal operations impacts are bounded by the values presented in Section 4.3 of this SA and require no specific additional analysis.