APPENDIX F
TRANSPORT AND MANAGEMENT OF PLUTONIUM FROM FOREIGN COUNTRIES

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F.1 Introduction

This appendix presents an assessment of the human health risks that could result from transporting plutonium materials from Europe (i.e., United Kingdom [UK] and France) to support reactor fuel production for the Versatile Test Reactor (VTR). The reactor fuel production would occur either at the Savannah River Site (SRS) or at the Idaho National Laboratory (INL). Given the projected processing efficiency of the VTR fuel fabrication (SRNL 2020), the VTR operation would require up to 34 metric tons of plutonium source materials over a 60-year span.[1] The United States has an excess plutonium inventory of more than 50 metric tons (GAO 2019) that is managed by the U.S. Department of Energy (DOE) and the National Nuclear Security Administration (NNSA). The excess DOE and NNSA plutonium would be sufficient to meet fueling needs for the VTR lifetime operation of 60 years. However, if that material cannot be made available or to supplement the domestic supply options, DOE has identified other potential sources from Europe.

This appendix considers that the plutonium would be transported by ship from the aforementioned countries in Europe to a U.S. seaport of entry. From the port of entry, the plutonium would be transported to SRS. Depending on DOE's decision on the location of feedstock preparation and fuel fabrication activities, the plutonium would remain at SRS for processing or be transported from SRS to the INL Site.

NNSA has prepared multiple environmental analysis documents (environmental impact statements [EISs], environmental assessments, and supplement analyses) for transporting various radioactive materials from foreign countries to the United States. Examples of these evaluations include the *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* (DOE/EA-1006) (DOE 1994), the *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) (DOE 2004), the *Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (FRR SNF EIS) (DOE/EIS-0218) (DOE 1996a), and the *Environmental Assessment for the Gap Material Plutonium – Transport, Receipt, and Processing* (Gap Material Plutonium EA) (DOE/EA-2024) (DOE 2015b). The analyses and actions described in this appendix are consistent with the example documents; the current analysis draws on the discussions and analyses in the FRR SNF EIS and Gap Material Plutonium EA.[2]

F.2 Scope

This appendix evaluates the potential environmental impacts from transporting plutonium across the global commons to the United States. Transferring packages of plutonium onto transporters at the port

[1] This is an upper estimate based on a driver fuel production efficiency of about 73 percent for fabrication without feedstock preparation. As the production efficiency improves, the need for the feedstock plutonium would be reduced.

[2] In 2004, DOE established the Global Threat Reduction Initiative, now called Material Management and Minimization, a vital part of the U.S. national security strategy of preventing the acquisition of nuclear materials by any organizations for the use in weapons of mass destruction. As part of the initiative, NNSA analyzed and implemented several activities to manage threats by removing and disposing excess weapon-usable and radiological materials. As the program evolved, NNSA recognized that there were certain materials that were not addressed by existing initiatives. These materials were called gap materials and included some plutonium.

of entry is also evaluated here. The impacts of transporting plutonium packages within the United States are not discussed in this appendix. However, they are explicitly evaluated in Appendix E.

Sources of Plutonium Materials

Two potential sources of plutonium materials suitable for VTR reactor fuel production have been identified (INL 2020). These include inventories of plutonium separated from spent nuclear fuel (SNF) from the magnesium alloy (Magnox) reactors and the advanced gas-cooled reactors in the UK, and plutonium separated from SNF from pressurized water reactors in France. In the UK, there are about 140 metric tons of separated plutonium (of which about 110 metric tons is UK owned) stored at the Sellafield nuclear site (NDA 2019). In France, there are about 81 metric tons of plutonium in oxide form (of which 65.4 metric tons are French owned). The plutonium is mainly stored at the La Hague used fuel reprocessing facility.

Actions in the Global Commons

The scope of the analysis essentially begins when the conveyance for transporting the plutonium material to the United States enters the global commons. In this analysis, the global commons is the ocean outside the territorial waters of a country.

Transport by Ship

This appendix analyzes transportation of plutonium material by ship across the global commons to a U.S. seaport (Joint Base Charleston-Weapons Station in South Carolina). Marine transport of plutonium would be conducted using chartered, exclusive-use ships,[3] in compliance with international and national transportation standards. To make efficient use of resources, the chartered ships may transport plutonium from either the UK or France or from both countries.

Ground Transport to the DOE Sites (Savannah River or Idaho National Laboratory Sites)

This EIS analyzes the ground transport of plutonium materials in specially design transporters from the Joint Base Charleston-Weapons Station to SRS or the INL Site. The analysis includes the potential impacts of transferring plutonium from the ship to the transporters.

Receipt at the DOE Sites (Savannah River or Idaho National Laboratory Sites)

Activities at DOE sites to receive the plutonium would include unloading the packages of plutonium, repackaging as needed to meet storage requirements, and moving the packages to a storage location.

Storage and Processing

Storage would be temporary, pending processing of the plutonium to prepare it as feedstock for the fabrication of VTR driver fuel. The processing would include removal of impurities (polishing) in the plutonium, especially removal of the ingrowth of americium-241 to a level suitable for the VTR fuel; i.e., an americium concentration of less than 1 weight percent (INL 2019).

F.3 Description of Activities

DOE is considering the use of existing supplies of reactor-grade plutonium that is currently available in the UK and France, as an option to the domestic supply, for use in VTR fuel production. This appendix conservatively evaluates the transport of up 34 metric tons of plutonium from either UK or France, or both countries, to support the lifetime operation of the VTR. The action is to transport sufficient plutonium materials in each shipment to support bi-annual operation of the VTR facility, which would lead

[3] Exclusive-use ships operate as chartered vessels and are not used for the transport of any other cargo other than the plutonium they are hired to transport.

to an estimate of 1.2 metric tons per transport. Plutonium transport would occur over a 60-year period, with a total of 29 shipments.

F.3.1 Shipments to the United States

Shipments of the needed plutonium materials to the United States would occur after (1) implementation of a contract or agreement between authorized representatives of the United States and the countries or nuclear facilities possessing the plutonium, (2) receipt of all data necessary to ensure safe handling and temporary storage, and (3) satisfactory resolution of any identified issues. At the foreign sites, the plutonium would be stabilized to meet the requirements of DOE-STD-3013 (DOE 2012) and placed into containers that are compatible with the requirements of the DOE SRS or INL storage facility. The containerized plutonium would be placed within packaging appropriate for the type and quantity of material, shipped to the United States,[4] and then to SRS, in compliance with requirements for safe transport of radioactive materials of the host country, the United States, and international organizations. These standards include the International Atomic Energy Agency (IAEA) Safety Standard Series Number SSR-6, *Regulations for the Safe Transport of Radioactive Material* (IAEA 2018), and 10 CFR Part 71, *Nuclear Regulatory Commission Regulations for Packaging and Transportation of Radioactive Materials*.

The mode of transport would be chartered and exclusive-use ships, which would deliver the plutonium to the seaport at Joint Base Charleston-Weapons Station, South Carolina (**Figure F–1**). The Joint Base Charleston-Weapons Station was selected for analysis in this *Versatile Test Reactor Environmental Impact Statement* (VTR EIS) because it serves as a seaport of entry for NNSA's Foreign Research Reactor Spent Nuclear Fuel (FRR SNF) Acceptance Program after an extensive analysis in the FRR SNF EIS (DOE 1996a). Its receipt of radioactive material has been analyzed in subsequent National Environmental Policy Act (NEPA) documents (e.g., DOE 2003b, 2006a, 2009, 2010, 2015b). The Joint Base Charleston-Weapons Station has an ongoing working relationship with DOE/NNSA, and the FRR SNF Acceptance Program is actively receiving shipments through this seaport. Since the program was established in 1996, over 60 SNF shipments have been received in the United States. Most of these shipments were received at the Joint Base Charleston-Weapons Station (NNSA 2013). The SNF casks have been offloaded from ships to trucks or rail cars and transported to DOE facilities (DOE 2009). In recent years, containers with gap material plutonium have also been received at the Joint Base Charleston-Weapons Station.

F.3.2 Packaging and Shipments

Transportation of plutonium would be conducted in accordance with national and international requirements for safety and safeguards or, if determined to be in the interest of national security, in accordance with approved exceptions to those requirements. The packaging used for plutonium transport would need to be acceptable to both the host country and the United States, meaning that packaging for which a certificate of compliance has been issued in one country would have to be accepted by a competent authority of the other country. In general, individual countries' regulations conform to the IAEA *Regulations for the Safe Transport of Radioactive Material* (IAEA 2018), thereby facilitating acceptance of certified packaging by another country.

[4] Typically, the country shipping the plutonium would be responsible for arranging transport packaging and loading the plutonium into transport vehicles; complying with safety and security requirements; coordinating with local and national officials; obtaining export approvals; and making any needed transit arrangements with countries through whose territorial waters transport ships may pass.

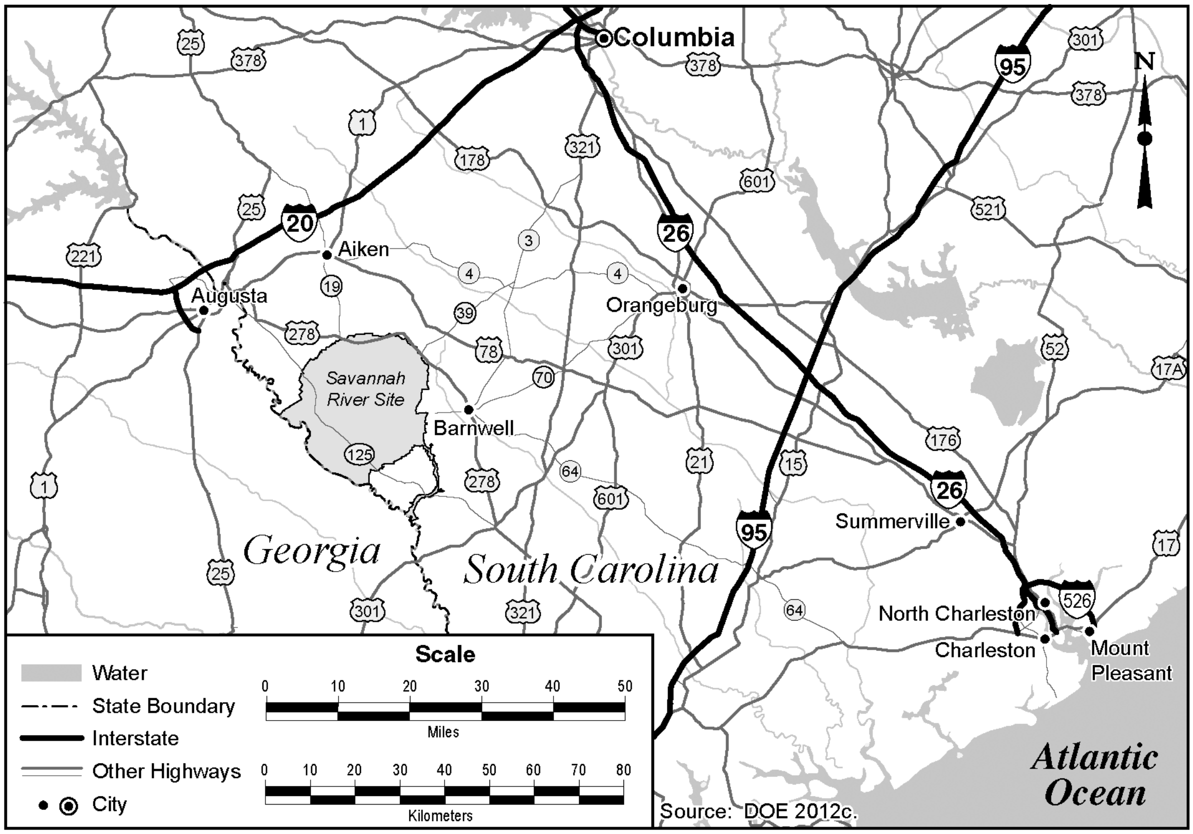

Figure F–1. Locations of the Joint Base Charleston-Weapons Station and Savannah River Site Overland Transport to Savannah River Site

All plutonium would be shipped using Type B packaging. Type B packaging must be designed and tested to withstand both normal transport and accident conditions.[5] Currently, there is only one representative Type B packaging[6] than can be used both internationally and within the United States. This packaging, the Model 9975, has been used in the United States for several years (DOT 2018:CoC USA/9975/B(M)F-96).

Model 9975 packaging (**Figure F–2**) includes an outside shell consisting of a stainless-steel, 35-gallon drum with a flange at the top for fasteners. Model 9975 packaging can hold a single container, composed of nested inner and outer stainless steel containers, of plutonium that has been stabilized pursuant to the requirements of DOE-STD-3013 (DOE 2012). One configuration housing welded containers meets DOE's standard for long-term plutonium storage (DOE 2012). A second configuration housing non-welded containers is used for interim storage. Containers of plutonium are secured in the package within primary containment vessels and secondary containment vessels that are surrounded by lead shielding and insulating material.

[5] 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 sub-criticality). With respect to accident conditions, there must be no substantial loss of function of the package after being subject to a series of tests that are conducted sequentially. These tests simulate being dropped from 30 feet onto an unyielding surface; being crushed or punctured; being exposed to a high heat (a temperature of at least 1,475 degrees Fahrenheit, as from a fire) for 30 minutes; and being immersed in water.

[6] In international and U.S. regulatory nomenclature, the term "package" means the packaging together with its radioactive contents as presented for transport. The term "packaging" means the assembly of components necessary to ensure compliance with packaging requirements. It may consist of one of more receptacles; absorbent materials; spacing structures; thermal insulation; radiation shielding; service equipment for filling, emptying, venting, and pressure relief; and devices for cooling or absorbing mechanical shocks.

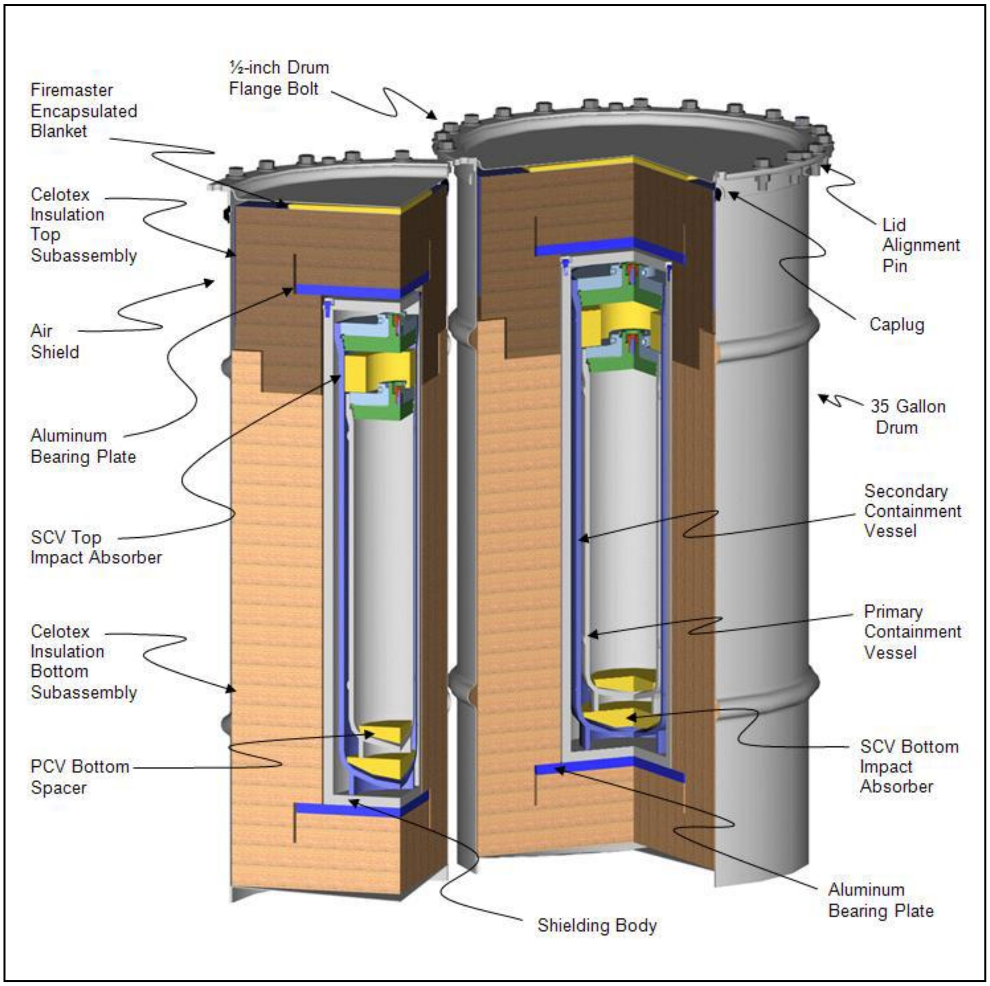

Figure F–2. Model 9975 Shipping Package

F.3.3 Ship Transport

At least 180 days before the tentative shipping date for transporting plutonium to the United States, DOE would establish a contract or agreement between DOE, representing the U.S. Government, and authorized representatives of the country or nuclear facility possessing the plutonium. Before shipment, teams of DOE or authorized contractor personnel would conduct foreign site visits that would include representative material examinations and facility and infrastructure assessments.

At the foreign sites, plutonium stabilized to meet the requirements of DOE-STD-3013 (DOE 2012), or similar characteristics meeting the requirements of the selected packaging, would be placed into containers compatible with the requirements of the U.S. storage facility. The containerized plutonium would be placed within packaging appropriate for the type and quantity of material. The packaged plutonium would be transported within the foreign countries to seaports of embarkation in compliance with local standards for safety and security. At the nuclear facility or seaport, the packages of plutonium would be securely mounted on pallets that would be secured within one or more International Organization for Standardization (ISO) shipping containers (ISO containers). Securing the packages on pallets facilitates transfer of the packages into and securing the packages within the ISO containers, removal from the ISO containers at the Joint Base Charleston-Weapons Station, and loading into specially design transporters for shipment to SRS. The ISO containers would be hoisted onto the transport ship at the foreign port and stowed securely within the ship's hold (see **Figure F–3**). DOE or contractor personnel may be present to facilitate arrangements and inspect packaging and loading operations.

Source: DOE 2009.

Figure F–3. ISO Containers Secured within the Hold of a Ship

The number of packages placed within an ISO container may vary. Considering criticality safety requirements, the physical dimensions of the packages and their groupings on pallets, the typical dimensions of ISO containers and overland transport vehicles, and worker radiation protection, each ISO container would contain up to 25 Model 9975 packages. Each expected shipment would consist of 15 ISO containers.

The chartered ship would be certified to meet the requirements of the *International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships* (INF Code) (SOLAS 1999). The requirements differ depending on the ship's INF Code classification. An INF Class 1 vessel may carry INF cargo with an aggregate activity of less than 108,000 curies. An INF Class 2 vessel may carry irradiated nuclear fuel or high-level radioactive waste (HLW) with an aggregate radioactivity of less than 54 million curies or plutonium with an aggregate radioactivity less than 5.4 million curies. An INF Class 3 vessel may carry irradiated nuclear fuel, HLW, or plutonium with no restrictions on aggregate radioactivity. Design and operational requirements for the three INF ship classes are addressed in a graded manner. They include those for vessel stability after damage, fire protection, temperature control of cargo spaces, structural strength of deck areas and support arrangements, cargo securing arrangements, electrical supplies, radiological protection equipment, ship management, crew training, and emergency plans (WNTI 2007).

Prior to each shipment, a threat assessment would be conducted in accordance with a security plan developed for the specific shipment. If determined necessary, armed security personnel could be onboard the transport vessel or an escort ship.

Although members of the general public would not be exposed to radiation during loading activities or during transport across the global commons to the United States, some members of the ship crew could be exposed to external radiation. Radiation doses potentially experienced by the crew would depend on the travel time to the Joint Base Charleston-Weapons Station, the loading and placement of ISO containers within the ship's hold, any material or cargo present that could provide shielding after stowage, and crew activities during loading and transit.

For shipments from the European countries (UK or France), a transport time of 15 days was assumed, based on the distances from European ports evaluated in the FRR SNF EIS (DOE 1996a) and assuming an average cruising speed of 12 knots consistent with experience with shipping FRR SNF (DOE 1998).

The number of crew members and their activities during loading operations reflect those addressed in the FRR SNF EIS (DOE 1996a) and Gap Material Plutonium EA (DOE 2015b). Ship crew members performing loading operations would be assisted by radiation protection personnel to reduce the potential for excessive radiation exposures.

While at sea, some of the crew members would enter the hold and be in the vicinity of the ISO containers to inspect the cargo and ensure it remains securely stowed (e.g., check the tightness of the cargo tie-downs). This activity would occur daily and represents the largest potential for radiation exposure to crew members. The radiation dose received by these crew members would depend on the levels of radiation emitted by the ISO containers, the number and placement of the ISO containers within the ship's hold (for shipments containing more than one ISO container), the inspection times, and the distance maintained from the ISO container during inspections. The external radiation rates for the shipment packages were assumed to be the regulatory limit of 10 millirem per hour at 2 meters. In reality, the dose rate is expected to be well below the regulatory limit. Because the vessel used for plutonium shipment would be exclusive-use, crew members performing the inspections would understand radiation safety principles, and unauthorized crew members would be excluded from the immediate area of the radioactive cargo.

Before entering the Joint Base Charleston-Weapons Station, a vessel carrying plutonium materials would communicate with appropriate personnel at the seaport to coordinate port entry and docking activities. Measures would be taken to ensure safety and security during the passage through the port entrance channel and travel within port reaches or turning basins. A pilot may board the vessel to assist the passage to the designated wharf. Escort vessels or tugs may also assist the passage.

F.3.4 Ship to Truck Transfer at the Joint Base Charleston-Weapons Station

At Joint Base Charleston-Weapons Station, specially designed transporters would be staged to await the arrival of the ship. In accordance with the security plan, if necessary, additional security would be provided at the dock during transfer of the cargo from the ship to the transporters. Upon arrival of the ship, authorized workers, assisted by ship crew members, would enter the hold; remove the tie-downs securing the ISO containers for the ocean voyage; attach rigging; remove the ISO containers from the hold using a crane; and place and secure the ISO containers on the transporters at the dock area. During incident-free transfer of ISO containers to the transporters, authorized personnel performing or assisting in the transfer would be exposed to external radiation from the containers. Members of the public and other workers at Joint Base Charleston-Weapons Station would be restricted from the vicinity of the unloading and transfer operations. Therefore, the public and other workers would not be exposed to radiation during incident-free unloading and package transfer activities.

F.3.5 Overland Transport to SRS

The plutonium-containing ISO containers received at Joint Base Charleston-Weapons Station would immediately be transported to SRS. The transport would be in a caravan-like configuration of 15 transporters with security adequate to prevent unauthorized removal of cargo. Because of the short travel distance between Joint Base Charleston-Weapons Station and SRS (less than 150 miles), no refueling or rest stops are expected.

F.3.6 Plutonium Receipt, Processing, Storage, and Disposition

At SRS, the plutonium would be received, temporarily stored at one of the K Area Complex locations (for example, the K Area Material Storage Area, illustrated in **Figure F–4**), and prepared as needed for the VTR fuel production, if feedstock preparation occurred at SRS. If feedstock preparation were to occur at the INL Site, the plutonium packages within the ISO containers would be temporarily stored at SRS and be reconfigured for transport to the INL Site, using DOE's Secure Transportation Asset (STA) specially designed transporters.

Figure F–4. Storage of Surplus Plutonium at the K Area Complex

F.4 Affected Environment

The environments that may be affected by the activities in Section F.3 include (1) the global commons that would be traversed by ships carrying the plutonium materials (Atlantic Ocean), (2) the seaport (Joint Base Charleston–Weapons Station) at which ships would dock, (3) the overland transportation routes, and (4) the location in the United States where the plutonium would be used. Descriptions of the affected environment are incorporated by reference from the Gap Material Plutonium EA (DOE 2015b) and are not repeated here. The Gap Material Plutonium EA provides detailed descriptions for the global commons, Atlantic Ocean, and the U.S. seaport of entry, Joint Base Charleston-Weapons Station. Appendix E of this EIS provides detailed descriptions of the overland transport routes and Chapter 3 describes the affected environments at SRS and the INL Site.

F.5 Analysis and Discussions

This section analyzes the environmental consequences of transporting plutonium from foreign countries to the United States, including impacts under incident-free and accident conditions from ship transport to a United States seaport (the Joint Base Charleston-Weapons Station). The impacts of the subsequent ground transport to SRS are provided in Appendix E of this EIS.

Consistent with Executive Order 12114, *Environmental Effects Abroad of Major Federal Actions*, this appendix does not address impacts from activities involving plutonium materials within the host countries. Countries shipping the plutonium materials would be responsible for complying with applicable laws and regulations associated with activities occurring within their borders.

The plutonium composition mixture could represent a range of characteristics with respect to the relative quantities of plutonium isotopes and americium with ingrowth isotopes of 25- to 40-year old materials. Primarily because of an increase in americium-241 over time (resulting from radioactive decay of plutonium-241), the older plutonium would present the largest health risk. The radionuclide distribution and specific activities of the European plutonium used for the analysis are presented in **Table F–1** (INL 2020).

Table F–1. Assumed Composition of Plutonium Material from United Kingdom and France

Radionuclide	*United Kingdom*	*France*
	Mass Fraction (percentage) (grams per gram of plutonium)	*Mass Fraction (percentage) (grams per gram of plutonium)*
Plutonium-238	0.22	2.10
Plutonium-239	69.42	62.00
Plutonium-240	26.96	25.00
Plutonium-241	0.86	4.00
Plutonium-242	2.54	6.60
Total Plutonium	100	99.7
Americium-241 [a]	4.68	8.40

[a] The americium fraction is per plutonium + americium-241.

Note: The mass fractions in the reference document are in the 2040 time frame for the UK fuel and at 25 years after plutonium separation for the French fuel.

Source: INL 2020:INL/MIS-20-57910 Rev. 1.

The 34 metric tons of plutonium evaluated in this EIS were assumed to be transported from either UK or France, or both countries, in 1.2 metric tons shipments, over 60 years of VTR operation. The plutonium would be shipped in Model 9975 packages. Twenty-five Model 9975 packages would be placed within an ISO container, a 20-foot standard shipping container. The quantity of plutonium actually placed within a package would depend on operational factors such as the total quantity of shipped material, the isotopic distribution of the plutonium, its chemical form (e.g., metal vs. oxide), and the presence of impurities. Depending on these operational factors, the quantity of plutonium shipped within a given package could range from levels less than the authorized capacity to levels approaching the maximum capacity.

Consistent with previous analysis in the *Surplus Plutonium Disposition Supplemental Environmental Impact Statement* (DOE 2015a), it was assumed that the average plutonium content within 25 Model 9975 packages would be about 80 kilograms or about 73 percent of the authorized capacity. Given this assumption, a 1.2 metric tons plutonium per shipment would require 15 ISO containers. Assuming all packages are filled to about 73 percent of authorized capacity, there would 375 Model 9975 packages per shipment.

F.5.1 Impacts on the Global Commons

F.5.1.1 Human Health Impacts from Ship Transport under Normal Operations

This section addresses incident-free human health impacts from shipping plutonium across the global commons. The general public would not receive a radiation dose from incident-free transport of plutonium by ocean vessel. However, radiological impacts would be experienced by the crews of the ships carrying the material from exposure to radiation during loading and off-loading the ISO containers and during daily inspections of cargo. The radiological impacts from cargo inspections would depend on the duration of the voyages. As discussed in Section F.3.3, based on the distances provided in the FRR SNF EIS (DOE 1996a), a 15-day voyage for a shipment from Europe is assumed.

As explained in Section F.3.3, operational procedures for loading and unloading ISO containers containing plutonium, and for cargo inspections during transport, would be the same as those in the FRR SNF EIS for ocean shipment of FRR SNF (DOE 1996a). Consistent with the FRR SNF EIS (DOE 1996a), the assumed crew duties are summarized in **Table F–2**. As shown, a chief mate, mate on watch, bosun, and two seamen are assumed to be exposed to radiation while loading the ISO containers onto the ship, and while unloading the ISO containers at the destination seaport (the Joint Base Charleston-Weapons Station). Consistent with the FRR SNF EIS (DOE 1996a), when loading or unloading ISO containers for maximum expected shipments, the crew members are assumed to be exposed to other ISO containers in the ship's hold. Doses received by each crew member are assumed to be the same as those evaluated in the FRR SNF EIS. This assumption is based on the same loading and unloading operations would be performed as those evaluated in the FRR SNF EIS, and the radiation levels at the exterior of the ISO containers are assumed to be at the regulatory limit, the same as evaluated in the FRR SNF EIS (DOE 1996a).

Table F–2. Assumed Crew Duties for Ocean Transport of Plutonium Materials

Crew Member	*Ship Loading Operations*	*Daily Cargo Inspections*	*Ship Unloading Operations*
Chief Mate	X	X	X
Mate on Watch	X		X
Bosun	X	X	X
Seaman(2)	X		X
Engineer		X	

The chief mate, bosun, and engineer are all assumed to participate in daily inspections of the cargo. Each of these crew members is assumed to perform one cargo inspection per day during each assumed 8-hour shift (three inspections total per day). For maximum expected shipments, it was assumed that crew members performing inspections on one ISO container would be exposed to radiation from other stowed ISO containers. The configuration of the ISO containers within a hold is a function of the hold characteristics (length, width, and height) with respect to those of the stowed containers. In the absence of specific information and consistent with the regulations on safe transport of radioactive materials (IAEA 2018), the assumptions on the inspection times and the distances at which the actions are carried out are based on information in the FRR SNF EIS (DOE 1996a). Each inspection was assumed to require 20 minutes per hold. Because there would be 15 ISO containers per shipment in a purpose-built ship (PNTL 2020) with five holds, the dose values provided in the FRR SNF EIS (DOE 1996a) were adjusted, accordingly.

The estimated doses per shipment to individuals and all involved crew members are shown in **Table F–3**.

Table F–3. Per-Shipment Crew Doses and Risks for Transporting Plutonium via Chartered Vessel

Impact	*Chief Mate*	*Mate on Watch*	*Bosun*	*Seaman* [a]	*Engineer*	*Total*
Plutonium Shipment – 15 ISO Containers per 15-Day Voyage						
Maximum dose (millirem) [b]	400	80	400	140	260	1,430
LCF risk [c]	2×10^{-4}	5×10^{-5}	2×10^{-4}	9×10^{-5}	2×10^{-4}	9×10^{-4}

ISO = International Organization for Standardization; LCF = latent cancer fatality.

[a] For each voyage, two seamen would receive radiation doses from the plutonium cargo; the doses presented are per seaman.

[b] Maximum doses were determined assuming that the radiation levels at the surfaces of all ISO containers correspond to the regulatory limit (10 millirem per hour at 2 meters from the ISO container surface).

[c] Risks were determined assuming a factor of 0.0006 LCFs per rem and are presented using one significant figure (DOE 2003a).

The results in Table F–3 show doses greater than 100 millirem per voyage. These results are a function of the assumptions in the FRR SNF EIS (DOE 1996a) regarding daily inspection and dose rates. These assumptions are conservative for the current exclusive-use ships and their radiation protection and inspection practices. The radiation doses associated with at-sea inspections could be reduced by minimizing the amount of time required for inspections and by maintaining an appropriate distance from the ISO containers, consistent with inspection requirements.

Notwithstanding these caveats, it is conceivable, as indicated in Table F–3, that some members of the crew who are not radiation workers could receive a radiation dose exceeding 100 millirem in a year. DOE would extend the program described in the mitigation action plan for FRR SNF (DOE 1996b)[7] or implement a similar program as that for the gap material plutonium shipments (DOE 2015b).

F.5.1.2 Human Health Impacts from Potential Shipping Accidents

There is a small probability of an accident on the open seas involving a vessel containing plutonium materials. There is an even smaller probability that the accident would be severe enough to result in release of radioactive material (e.g., a collision with another ship that crushes packages of plutonium, followed by a fire sufficient to release radioactive material as respirable particles to the atmosphere). The probability of a severe port accident that would result in the release of plutonium is 5×10^{-9} per ship arrival in port (DOE 1996a). The probability of this accident occurring in coastal waters or the open ocean is even lower (IAEA 2001). The probability is smaller than the probability that DOE considers for analysis of maximum reasonably foreseeable accidents (1×10^{-7} or 1 chance in 10 million) (DOE 2002). Therefore, the consequences of this accident are not evaluated in this VTR EIS. This severe port accident was analyzed in previous NEPA documents addressing shipment of radioactive materials (e.g., DOE 1996a, 2006a, 2009, 2010).

F.5.1.3 Other Impacts from Ship Transport

There would be no release of radioactive material under incident-free transport, meaning there would be no radiological impacts on the global commons, including impacts on marine biota and fisheries. If an incident were to occur (for example, a collision with another ship or foundering), environmental impacts could result. Packages of plutonium could rupture and be released into the ocean.[8] The response to, and potential impacts of, such an accident would be different, depending on the location and condition of the packages following the accident (DOE 1994, 2004). Packages that did not sink below about 660 feet could be located and recovered. Undamaged packages that sink deeper than about 660 feet could be breached by the pressure of the overlying water or by corrosion, which would release their contents. As discussed in the Gap Material Plutonium EA (DOE 2015b), a number of previous NEPA evaluations have considered the potential radiological impacts of a release of radioactive material from an accident at sea. The analyses concluded that some marine organisms directly exposed to radioactive material could receive large doses of radiation and that some loss of marine life would occur. They further concluded that because of the large volumes of water involved, mixing mechanisms, existing background radiation levels, and radiation-resistance of aquatic biota, the radiological impact on marine life would be localized and minor.

Additional discussion of potential impacts from ship transports are provided in the Gap Material Plutonium EA (DOE 2015b). As noted in that EA, there is a possibility that a ship transporting plutonium

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[7] Under the mitigation program applied to shipments of FRR SNF (DOE 1996b), DOE requires that its shipping contractor obtain radiation surveys of FRR SNF casks before shipment, and use these data to ensure that the estimated dose to any crew member does not exceed 100 millirem per year. DOE also maintains a database of the actual radiation surveys for each cask and shipment, and includes clauses in its shipping contracts to minimize the likelihood that any member of a ship's crew would be exposed to more than 100 millirem during a single year.

[8] For the 5-year period between 2010 and 2014, 22 large ship collisions were reported worldwide; approximately 5 per year (Allianz 2015). The frequency of serious ship collisions is estimated at about 3.9×10^{-8} per nautical mile (IAEA 2001).

for DOE or NNSA could strike and kill or injure a federally protected Atlantic coast species (e.g., North Atlantic right whale, loggerhead sea turtle, or manatee). However, the impact on these species is expected to be minimal due to the small number of shipments (less than one per year) and adherence to speed restrictions in coastal waters and port entrance channels.

F.5.2 Impacts at the Seaport of Entry –Joint Base Charleston-Weapons Station

F.5.2.1 Human Health Impacts under Normal Port Operations

Radiation doses at the seaport would be received by the ship's crew, as well as by port workers involved in removing the ISO containers from the vessels and placing the ISO containers on the dock or on the specially designed transporters. There would be no radiation doses received by members of the public from incident-free activities at the Joint Base Charleston-Weapons Station. Activities at the seaport would occur at a secure military base. Unauthorized personnel would be excluded from locations where the ISO containers would be removed from the vessel (see Section F.3.4).

The types of involved workers participating in transfer of the ISO containers from a ship to the dock at Joint Base Charleston-Weapons Station are assumed to be the same as those evaluated in the FRR SNF EIS (DOE 1996a) for receipt of FRR SNF. It is assumed that the ISO containers unloaded from a ship would be transferred to a trailer at the dock. Involved workers include those responsible for inspection of the delivered cargo, transferring the cargo to the dock (cargo handlers), and moving the ISO containers to a staging area (staging personnel). The same radiation doses for transfer of a single ISO container were assumed for these workers as those evaluated in the FRR SNF EIS, because the same basic port activities would occur (inspection, unloading, and staging). The radiation levels of the ISO containers were assumed to be at the regulatory limit, the same as those in the FRR SNF EIS (DOE 1996a). Given these assumptions, doses and risks from shipping 15 ISO containers of plutonium are presented in **Table F–4**.[9] No worker is expected to receive a dose exceeding 100 millirem, even if all shipments were to occur in a single year. The total dose among all workers is projected to be 0.20 person-rem, with no latent cancer fatalities (LCFs) associated with these doses (calculated values: 1×10^{-4}).

Table F–4. Incident-Free Impacts for Unloading 15 ISO Containers of Plutonium Materials from Chartered Ships [a, b]

	Maximally Exposed Worker		*Worker Population*	
Risk Group [c]	***Dose (millirem)***	***Risk (LCF)*** [d]	***Dose (person-rem)***	***Risk (LCF)*** [d]
Inspectors (6)	20	1×10^{-5}	0.08	5×10^{-5}
Port Cargo Handlers (4)	7	4×10^{-6}	0.02	1×10^{-5}
Port Staging Personnel (5)	6	4×10^{-6}	0.07	4×10^{-5}
Maximum [e]	20	1×10^{-5}	NA	NA
Total	NA	NA	0.20	1×10^{-4}

LCF = latent cancer fatality; NA = not applicable; rem = roentgen equivalent man.

[a] ISO container surface dose rates were assumed to be at the regulatory limit (10 millirem at 2 meters from the container surface).

[b] These results are based on the conservative assumption that each voyage carries more than one ISO container, resulting in larger doses to port personnel because of the combination of radiation fields surrounding each of the ISO containers.

[c] Numbers in parentheses are the assumed numbers of exposed personnel in each risk group.

[d] LCF risks are based on 0.0006 LCFs per rem or person-rem and are presented using one significant figure (DOE 2003a).

[e] The highest dose and risk among the risk groups.

Note: Totals may not equal the sums of table entries due to rounding.

Source: DOE 1996a for per-container radiation dose values.

[9] Doses received by cargo handlers and staging personnel were based on the assumption that ISO container unloading activities would require 65 minutes per ISO container. Experience with the FRR SNF Acceptance Program suggests that the actual unloading time would be closer to 20 minutes per ISO container (DOE 2009). The less time required to unload the ISO containers, the smaller the dose received by cargo handlers and other involved personnel.

F.5.2.2 Human Health Impacts from Potential Accidents Involving Port Operations

There is a small probability of a port accident involving a vessel containing plutonium, and an even smaller probability that the accident would be severe enough to result in release of radioactive material (e.g., a collision with another ship that crushes packages of plutonium, followed by a fire sufficient to release radioactive material as respirable particles to the atmosphere). The probability of a severe port accident that would result in the release of plutonium is 5×10^{-9} per ship arrival in port (DOE 1996a). This is smaller than the probability that DOE considers for analysis of maximum reasonably foreseeable accidents (1×10^{-7}, or 1 chance in 10 million) (DOE 2002). The consequences of this accident were not evaluated in this VTR EIS.

Other accidents could also occur during port operations, ISO container unloading, container staging, and container loading on transporters. It is conceivable that, for example, an ISO container could be dropped onto the dock while being unloaded from a ship. Any potential human health risk to a worker from such hypothetical incidents would only be associated with the physical forces of contact and not from release of radioactive material. All plutonium would be shipped within Type B packages designed and constructed to meet hypothetical accident conditions of transport without release of the package contents. Package tests include being dropped from 30 feet onto an unyielding surface; being crushed or punctured; being exposed to a high heat as from a fire; or being immersed in water. These tests and the design and construction of the packages would exceed the forces on a package that could be imposed by a dropped-package scenario at the dock.

F.5.2.3 Other Impacts from Port Operations

Shipments of plutonium materials would not affect the volume of ship traffic into or out of the port area of Charleston, meaning the shipments would have little effect on resource areas such as water quality, marine life, or socioeconomics. No more than 29 ocean voyages are expected for the maximum plutonium need of 34 metric tons over a period of 60 years. Even if all voyages occurred in a single year, 29 ocean voyages would represent about 1 percent of the 1,944 large commercial vessel and cruise ship calls at the port of Charleston in 2011 (DOT 2013a, 2013b).[10]

Shipments of plutonium would use existing infrastructure, with no need for construction or modification of Joint Base Charleston-Weapons Station facilities and no land disturbance that could potentially affect land use, biological resources, cultural resources, or geologic media. Under incident-free transport conditions, there would be no release of radioactive material to air or water. Nonradioactive waste would not be generated beyond that associated with normal operation of ships and port facilities. No pollutants, including greenhouse gases, would be discharged to the air beyond those normally released during ship and port operations. No water would be withdrawn from or discharged to surface water or groundwater beyond that authorized for normal operation of ships and port facilities. Shipments of plutonium would not affect socioeconomic conditions at the seaport. Work would be accomplished using existing DOE, seaport, and contractor personnel.

Members of the public would be placed at no radiological risk during incident-free operations because a security perimeter would be established around the ship unloading and package transfer operations, and members of the public and unauthorized seaport personnel would be excluded from the perimeter. Because all members of the public would be thus protected from radiological risk, no disproportionately high and adverse radiological risks would occur among low-income and minority populations in the vicinity of the seaport.

[10] To reach the Joint Base Charleston-Weapons Station, all ships must travel up the Cooper River past the port of Charleston. The number of annual military vessel calls at the Joint Base Charleston-Weapons Station is classified.

F.5.3 Impacts from Receipt of Plutonium Materials at the Savannah River Site

It was assumed that plutonium transported to SRS would be received and temporarily stored at the K Area Complex, where the plutonium would be unloaded from ISO containers and material control and accountability measurements taken. The packages would be transferred on metal pallets to the designated storage location if feedstock preparation for reactor fuel production is to occur at SRS. If feedstock preparation is to occur at the INL Site, the plutonium packages would be unloaded from the ISO containers and reconfigured for transport to the INL Site in STA transporters (e.g., Safeguards Transporter).

All activities involving plutonium receipt would be conducted in accordance with established radiation safety procedures and standards. Administrative and technical controls would be implemented to ensure that radiation dose rates to workers would be monitored, maintained to levels within DOE standards and guidelines, and reduced to as low as reasonably achievable levels.

F.5.3.1 Impacts on Workers

Impacts on workers could result from receiving plutonium and placing it into storage. Worker doses from receipt of plutonium would be comparable to those of daily activities for the facility operations at SRS K Area Complex, as described in Chapters 3 and 4 of this VTR EIS.

F.5.3.2 Impacts on the Noninvolved Workers and the Public

All plutonium received at SRS would be contained within Type B packages, and there would be no releases to the environment during normal receiving activities. In addition, noninvolved workers and the public would not be in direct proximity to the storage packages. The K Area Complex is more than 5.5 miles from the SRS boundary. Therefore, there would be no radiological impacts on noninvolved workers and the public from incident-free plutonium receipt.

F.6 Intentional Destructive Acts

The plutonium to be used for fabricating VTR fuel represents a potential target for diversion or terrorist actions. The following discussion relates to such intentional destructive acts associated with the transport of plutonium to the United States and its use in the VTR and rendering it unusable for weapons production.

F.6.1 Intentional Destructive Acts on the Global Commons

Maritime areas where acts of terrorism or piracy are more likely would be avoided to the extent practical. Ships passing thorough these areas would be provided with additional security as necessary. About 80 percent of all acts of piracy, for example, take place in the territorial waters of sovereign nations. In 2007, the locations with the most incidents of piracy included waters near Indonesia, Nigeria, and Somalia (Petretto 2008). Transport of material from European countries would not travel near these countries. If an intentional destructive act were to occur at sea, potential impacts would primarily be to onboard personnel. Potential impacts could range from fatalities associated with an explosion or drowning to lesser impacts from radiation exposure to untrained or uninformed personnel in the immediate vicinity of the transportation packages containing plutonium. Potential radiological impacts on people in the proximity of this accident would be similar to the analysis of intentional destructive acts during overland transport, as discussed below in Section F.6.2.

F.6.2 Intentional Destructive Acts in the United States

In accordance with DOE NEPA guidance (DOE 2006b), an analysis was performed in a classified appendix to the *Environmental Assessment for the U.S. Receipt and Storage of Gap Material – Plutonium and Finding of No Significant Impact* (DOE 2010) to consider the potential impacts of intentional destructive acts for activities related to plutonium transport. A range of scenarios involving the release of plutonium was evaluated in that EA. Each scenario involves an action by intruders during the transportation of packages within the United States. The analysis of intentional destructive acts performed for the *Environmental Assessment for the U.S. Receipt and Storage of Gap Material – Plutonium and Finding of No Significant Impact* is applicable to the action in this VTR EIS and is, therefore, incorporated by reference.

F.6.3 Mitigation of Intentional Destructive Acts

The likelihood of an intentional destructive act during transport of gap material plutonium is minimized by the security measures that would be taken to reduce knowledge of and access to the shipments. In the aftermath of the September 11, 2001 attacks, DOE, the U.S. Department of Defense (DOD), and the U.S. Department of Homeland Security implemented measures to minimize the risk and consequences of potential terrorist attacks on DOE and DOD facilities and U.S. ports. Safeguards applied to protecting facilities that contain nuclear material involve a dynamic process of enhancement needed to meet evolving threats. DOE and DOD continually re-evaluate security scenarios involving intentional destructive acts to assess potential vulnerabilities and identify improvements to security procedures and response measures. Security at these facilities is a critical priority for both DOE and DOD, which continue to identify and implement measures to deter attacks and defend against them. DOE and DOD maintain a system of regulations, orders, programs, guidance, and training that forms the basis for maintaining, updating, and testing site security to preclude and mitigate any postulated terrorist actions (Brooks 2004; DHS 2006; Pub. L. 107-296, 33 CFR Part 165, and 33 CFR Part 334).

F.7 Cumulative Impacts

Council on Environmental Quality regulations (40 CFR Parts 1500-1508) define cumulative impacts as effects on the environment that result from implementing the Proposed Action or any of its alternatives when added to other past, present, and reasonably foreseeable future actions, regardless of what agency or person undertakes the other actions (40 CFR 1508.7). The cumulative impacts of an action can be viewed as the total impacts on a resource, ecosystem, or human community of that action and all other activities affecting that resource irrespective of the source. This analysis of cumulative impacts emphasizes public health and safety impacts associated with the transport of plutonium for use as VTR driver fuel.

Transport to U.S. Seaports. Each year, there are several million worldwide shipments of radioactive materials using trucks, trains, ocean vessels, aircraft, and other conveyances, including large numbers of shipments across the global commons. Shipments of plutonium to the United States for use as VTR driver fuel would represent only a fraction of these worldwide shipments.

Collective radiation doses and risks to crews and populations for incident-free transport of 34 metric tons of plutonium from foreign countries to U.S. seaports are summarized in **Table F–5**. This table also lists the doses and risks to ship crews and dock workers from shipment of: (1) 100 kilograms of gap material plutonium by ocean vessel, as evaluated in the 2010 *Environmental Assessment for the U.S. Receipt and Storage of Gap Material – Plutonium* (DOE 2010); (2) 5 metric tons of highly enriched uranium (HEU) by ocean vessel, as evaluated in the 2006 *Supplement Analysis for the Air and Ocean Transport of Enriched Uranium between Foreign Nations and the United States* (DOE 2006a); (3) shipment of 900 kilograms of gap material plutonium in the Gap Material Plutonium EA (DOE 2015b); and (4) shipment of FRR SNF by ocean vessel under the FRR SNF Acceptance Program. Some personnel could be exposed to radiation from shipments of plutonium materials, as well as from shipment of FRR SNF or HEU in unirradiated nuclear fuel. Doses thus received as part of plutonium shipments would be mitigated, as discussed in Section 4.9 of the Gap Material Plutonium EA (DOE 2015b).

Table F–5. Cumulative Radiation Doses and Risks for Incident-Free Marine Transport of Radioactive Shipments to U.S. Seaports

Risk Receptor (scenario)	***Radiation Dose (person-rem)***	***Risk (LCF)*** [a]
Ship crew, 900 kilograms of gap material plutonium (Proposed Action) [b, c]	2.8 to 4.1	2×10^{-3}
Dock handlers, 900 kilograms of gap material plutonium (Proposed Action) [b, c]	0.20 to 0.26	1×10^{-4} to 2×10^{-4}
Ship crew, 100 kilograms of gap material plutonium [b, c, d]	1.4	8×10^{-4}
Dock handlers, 100 kilograms of gap material plutonium [b, c, d]	0.67	4×10^{-4}
Ship crew, 5,000 kilograms of unirradiated HEU [e]	0.030	2×10^{-5}
Dock handlers, 5,000 kilograms of unirradiated HEU [e]	0.13	8×10^{-5}
Ship crew, FRR SNF [f]	75.4	5×10^{-2}
Dock handlers, FRR SNF [f]	8.2	5×10^{-3}
Ship crew, 34 metric tons of plutonium from Europe [b, g, h]	**40.6**	$\mathbf{2 \times 10^{-2}}$
Dock handlers, 34 metric tons of plutonium from Europe [b, g, h]	**4.9**	$\mathbf{3 \times 10^{-3}}$
Totals	**134 to 135**	$\mathbf{8 \times 10^{-2}}$

FRR = foreign research reactor, HEU = highly enriched uranium, LCF = latent cancer fatality, rem = roentgen equivalent man; SNF = spent nuclear fuel.

[a] Risks were determined using a dose-to-risk factor of 0.0006 LCFs per person-rem and are presented using one significant figure (DOE 2003a).

[b] Conservatively assumes a surface radiation dose at International Organization for Standardization container or package array surfaces of 10 millirem per hour at 2 meters.

[c] The 2015 *Environmental Assessment for Gap Material Plutonium—Transport, Receipt, and Processing and Finding of No Significant Impact* (DOE/EA-2024) (DOE 2015b) addressed shipment of 900 kilograms of gap material plutonium to the United States under a ship transport alternative. It considered 12 shipments of gap material plutonium by chartered vessel.

[d] The 2010 *Environmental Assessment for the U.S. Receipt and Storage of Gap Material – Plutonium and Finding of No Significant Impact* (DOE/EA-1771) (DOE 2010) addressed shipment of 100 kilograms of gap material plutonium to the United States under a ship transport alternative and an aircraft transport alternative. Only the ship transport alternative is included here because the aircraft transport alternative has not been implemented.

[e] The option of shipping the same 5,000 kilograms of unirradiated HEU by military cargo or commercial aircraft was also assessed. Air shipment of all unirradiated HEU was projected to result in a collective dose to air crew members of up to 1.1 person-rem and a collective dose to ground cargo workers of up to 0.51 person-rem. The corresponding risks were 7×10^{-4} LCF and 3×10^{-4} LCF, respectively (DOE 2006a).

[f] Assumes a radiation dose of 10 millirem per hour at 2 meters for SNF, including shipment of gap material SNF (DOE 2009), and updating the dose-to-LCF factor from that assumed in the FRR SNF EIS (DOE 1996a) to 0.0006 LCFs per person-rem (DOE 2003a).

[g] The impacts values are based on the per-shipment values of 15 ISO containers per transport in Tables F–3 and F–4.

[h] Transport of 34 metric tons requires 28 shipments of 15 ISO containers and one shipment of five ISO containers. Therefore, the values reflect 28.33 times the per shipment impacts in Tables F–3 and F–4.

Note: Totals may not add due to rounding. To convert kilograms to pounds, multiply by 2.205, and metric tons to tons, multiply by 1.1023.

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