DOE/EA-0841

ENVIRONMENTAL ASSESSMENT OF THE IMPORT OF RUSSIAN PLUTONIUM-238

June 1993

U.S. Department of Energy

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1.0 PURPOSE AND NEED FOR ACTION

The United States (U.S.) is proposing to purchase plutonium-238 (Pu-238) from the Russian Federation (Russia) for use in the Nation's space program. The National Environmental Policy Act of 1969 (NEPA), as amended, requires the assessment of environmental consequences of all major Federal actions that may significantly affect the quality of the human environment. Accordingly, the U.S. Department of Energy (DOE) prepared this Environmental Assessment (EA) to identify and evaluate the environmental consequences of importing Pu-238 fuel from Russia, and of the initial transport and processing of such fuel within the U.S., as necessary, to add the fuel to the existing U.S. inventory. Since the proposed action involves ocean transport, DOE also considered the environmental consequences of this action on the global commons in accordance with Executive Order 12114 and DOE Guidelines for Compliance with Executive Order 12114.

1.1 BACKGROUND

The Atomic Energy Act of 1954, as amended, authorized DOE to develop nuclear energy systems for its own programs and in support of other organizations. The Act also authorized DOE to produce such systems and directed DOE to take necessary actions to assure such systems are used in a safe manner. Under this charter, DOE has developed and provided Pu-238 radioisotope power systems for space and terrestrial missions for the past 30 years.

Radioisotope thermoelectric generators (RTGs) fueled with Pu-238 have provided electrical power for a number of National Aeronautics and Space Administration (NASA) space missions. Due to the relatively long half-life of Pu-238 (87.8 years) and the absence of any moving parts, RTGs provide long-term reliable sources of spacecraft electrical power. In addition, Light-Weight Radioisotope Heater Units (RHUs) fueled with Pu-238 can be used to provide local heating of spacecraft components. The Galileo and Ulysses spacecrafts, launched in 1989 and 1990 to study Jupiter and the polar regions of the Sun, respectively, are powered by Pu-238 fueled RTGs. These missions could not be accomplished without RTGs due to mission duration and distance from the Sun, rendering the use of chemical batteries or solar panels infeasible. The scientific and technical knowledge gained from these missions is vastly expanding our knowledge of the universe. Future NASA missions for which RTGs are being considered include the Cassini mission, designed to explore Saturn and its moons, planned for launch in 1997. Other interplanetary missions are in the planning stages by NASA for launch in the time frame beyond 1997.

The NASA updated strategic plan for the Solar System Exploration Program identified a series of space exploration missions to achieve national goals, including a broadly based set of individual missions ranging from flybys, to orbiters and simple landers, to sophisticated robotic missions. The availability and use of Pu-238 fueled systems will make these planetary exploration missions possible. A series of precursor missions to the Moon and Mars has also been considered. From the broad set of potential missions, NASA has identified missions that will most likely be supported and approved, and for which Pu-238 fueled RTGs and RHUs are being considered (NASA 1992). These missions would require a total of 132 kilograms (kg) of Pu-238 through the year 2000. Of the 64 kg of usable Pu-238 in the current DOE inventory, approximately one half is allocated to the Cassini mission. Since the steps involved in transforming Pu-238 in the U.S. inventory into assembled and fully qualified RTGs and RHUs require several years, such Pu-238 must be made available years ahead of planned mission launches.

The operations and facilities which have been involved in the production and processing of all U.S. Pu-238 are located at the Savannah River Site (SRS), with subsequent fuel fabrication and assembly processes leading to a fueled RTG currently carried out at Los Alamos National Laboratory (LANL) and Mound Laboratory. The production and processing of Pu-238 at SRS has been performed in facilities whose primary function has been the production of defense nuclear materials.

Previous production of Pu-238 at SRS involved the irradiation of neptunium-237 (Np-237) targets with neutrons in a nuclear reactor. The capture of a neutron by the Np-237 forms Np-238, which in turn decays with about a 2-day half-life to Pu-238. Following irradiation in the nuclear reactor, the targets are allowed to decay prior to being dissolved in H-Canyon facilities and processed to recover Pu-238. The recovered Pu-238 is purified and converted to Pu-238 dioxide before being shipped offsite for further fabrication. The Np-237 is produced by successive neutron capture by uranium-235 (U-235) in nuclear reactor fuel during the operation of a reactor, and recovered during the processing of the spent nuclear fuel in the SRS H-Area Canyon reprocessing facility. The recovered Np-237 is purified, converted to oxide form and fabricated into targets for irradiation.

The SRS facilities are also used to reprocess, reclaim and blend Pu-238 inventory material in various oxide and scrap forms to meet product specifications, as will be done for the Cassini mission. An EA issued previously by DOE addresses the processing at SRS and fabrication at LANL of the Pu-238 currently in the U.S. inventory (DOE 1991c).

1.2 PURPOSE OF AGENCY ACTION

The purpose of this agency action is to supplement the U.S. inventory of Pu-238 available as heat source fuel. This would enhance DOE's ability to satisfy near-term mission requirements for NASA outer planetary exploration programs and other activities until alternative sources of supply are identified. No other radioisotope is available, qualified, or economically and technically practical to fulfill the unique requirements imposed by the proposed missions identified. DOE has the charter and responsibility to assure that it maintains the capability to provide the Pu-238 needed to support these National missions.

1.3 NEED FOR AGENCY ACTION

The availability of SRS facilities for continued production of Pu-238 in the near-term has changed. The DOE is in the process of planning the reconfiguration of the Nuclear Weapons Complex to be smaller, less diverse, and less expensive to operate than the present configuration (DOE 1991a and d). This activity is being addressed in a Programmatic Environmental Impact Statement (PEIS) currently in preparation. The final configuration of the Complex will include consideration of a replacement for the current tritium production capability provided by the existing SRS production reactors. A replacement tritium production facility could also possibly be used for Pu-238 production. Thus, the future approach to Pu-238 production is uncertain and will not be decided for several years. In addition, other changes are planned in the production complex that will have a major impact on Pu-238 production and processing. These include:

- The K-Reactor at SRS has been placed in cold standby. Future Pu-238 production in this reactor is not currently being planned.

- It has been decided to phase out reprocessing of Highly Enriched Uranium (HEU) from the Weapons Complex. This will result in the shutdown of H-Canyon and related facilities at SRS and the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL) within the next 5 to 6 years.

Shutdown of K-Reactor will eliminate both the irradiation of the Np-237 targets and the availability of the driver fuel as a source of new Np-237. Phaseout of H-Canyon reprocessing will eliminate the capability to obtain the Np-237 from the driver fuel; to process the irradiated targets to recover Pu-238 and Np-237; and to process and recycle Pu-238 scrap material. Shutdown of the ICPP will eliminate the potential of obtaining Np-237 from reprocessing Naval Reactor spent fuel. If these existing facilities were to continue operation with the sole mission of supplying Pu-238, the unit cost of the product to the using programs and agencies would increase very substantially.

The DOE is evaluating the issue of how and at what cost it will provide Pu-238 for projected NASA space missions. The reduction by about half of the U.S. inventory to support the Cassini mission, and the recent decisions affecting future production and processing at existing DOE facilities require the consideration of alternate sources for Pu-238 in the near-term. These potential interim sources include Pu-238 of foreign origin.

2.0 PROPOSED ACTION AND ALTERNATIVES

2.1 PROPOSED ACTION

The proposed action is for DOE to import up to 40 kg of Pu-238 fuel (isotope mass) in the dioxide form from Russia over the next 5 years in 5 kg increments in order to supplement the current inventory to help satisfy mission requirements through the year 2000. The Administration has granted DOE approval to negotiate this purchase.

The proposed action includes the transportation of Russian Pu-238 in 5 kg increments by Russian flagged vessel from St. Petersburg, Russia, to a U.S. port of entry. The U.S. will supply Mound 1 Kilowatt Thermal (KW) Packages for these shipments. The Mound 1 KW Packages are certified by DOE and the U.S. Department of Transportation (DOT) for domestic and international use. From the U.S. port of entry, the shipments will be transported by DOE Safe Secure Trailer (SST) to either the SRS in South Carolina or LANL in New Mexico. Any imported fuel not meeting U.S. specifications would undergo limited processing at SRS, as described in DOE/EA-0534 (DOE 1991c) for the Cassini mission Pu-238 fuel processing campaign, and be added to that portion of the existing U.S. Pu-238 inventory located at SRS. This processing would remove any impurities from the Russian fuel. It is expected that only approximately the first 5 kg of the 40 kg would require processing at SRS, although for purposes of this EA the impacts of transporting all 40 kg of Pu-238 to SRS for processing and storage have been analyzed. Imported Pu-238 meeting U.S. specifications would be added to that portion of the existing U.S. Pu-238 inventory located at LANL. This proposed action includes transportation from the port at St. Petersburg to either SRS or LANL.

2.2 ALTERNATIVES TO THE PROPOSED ACTION

The DOE has considered a number of alternatives to the proposed action. These include alternatives to production and sources of supply, and alternative ports of entry for transporting Pu-238 for the proposed action.

2.2.1 Pu-238 Production and Supply Alternatives

Potential near-term alternatives to supplement the current supply of Pu-238 include:

- K-Reactor Alternative

  This alternative consists of dedicated production in the K-Reactor at SRS. In accordance with the Record of Decision by the Secretary of Energy on the Final Environmental Impact Statement on the continued operation of K-, L-, and P-Reactors, (DOE 1990), K-Reactor was to undergo a period of operational testing and then be placed in cold standby, with its operation in the future determined by the need for tritium in support of the DOE Weapons Complex, rather than by Pu-238 requirements. Subsequently, following a curtailed period of operational testing, the K-Reactor was placed in cold standby in March 1993. The use of K-Reactor solely for Pu-238 production would result in high unit cost of the Pu-238 compared to the proposed action and other alternatives. The use of K-Reactor to produce Pu-238 would require a reversal of current DOE planning and would only be considered if the purchase of

Russian Pu-238 was not consummated, or if a requirement for a large amount of Pu-238 were to become necessary.

- Purchase from Great Britain Alternative

  Preliminary discussions indicate that small quantities (less than kg quantities) of Pu-238 could be made available from Great Britain, but larger quantities would require extensive investments by Great Britain in its facilities which would require several years to construct. Further discussions between the U.S. and Great Britain would be required before this option could be considered. Given that only the U.S. and Russia have significant Pu-238 production capability and inventory, this alternative is not considered viable if DOE is to be responsive to NASA's needs as they arise in the near term.

- Purchase from France Alternative

  Preliminary discussion indicates that Pu-238 could be made available from France in the late 1990s. As under the previous alternative, this alternative is not considered viable given the need to be responsive to NASA's needs as they arise.

- No Action Alternative

  The No Action Alternative consists of not purchasing the Russian Pu-238 fuel, nor providing additional supply by other alternatives. Under the No Action Alternative, projected Pu-238 mission requirements through the year 2000 could not be satisfied with the current U.S. inventory and some of the space missions considering Pu-238 as planned by NASA would not be feasible.

2.2.2 Transportation Alternatives

The proposed action could be carried out using alternative U.S. ports of entry for subsequent shipment to either SRS or LANL. DOE identified 36 ports of entry on the Atlantic, Gulf, and Pacific coasts of the U.S. for consideration as alternatives, listed in Table 2-1. As addressed in this EA these port locations include both civilian and U.S. Naval port facilities in the listed vicinity. Although the alternatives considered include all major ports on the three coasts, the majority of which are located in the larger metropolitan areas, smaller ports with low population densities in the port region were also included to span the range of population densities in the evaluation of alternatives.

Factors considered by DOE in the evaluation of alternative ports of entry included:

- Ocean distance from St. Petersburg to port of entry
- Highway distances from port of entry to SRS and LANL
- Transportation health risk (including the ocean transport to the port of entry and highway transport from the port of entry to SRS or LANL)
- Experience factors related to Russian familiarity with port facilities, and port experience with international cargo vessels importing radioactive materials

Table 2-1

Alternative Ports of Entry Considered[a]

Atlantic Coast Ports	Gulf Coast Ports	Pacific Coast Ports
Baltimore, MD	Beaumont, TX	Long Beach, CA
Boston, MA	Corpus Christi, TX	Los Angeles, CA
Hampton Roads, VA	Galveston, TX	Oakland, CA
New York, NY	Gulfport, MS	Port Hueneme, CA
Philadelphia, PA	Houston, TX	Richmond, CA
Wilmington, DE	Mobile, AL	Sacramento, CA
Charleston, SC	New Orleans, LA	San Diego, CA
Jacksonville, FL	Port Arthur, TX	San Francisco, CA
Miami, FL	Tampa, FL	Stockton, CA
Morehead City, NC		Portland, CA
Port Everglades, FL		Seattle, WA
Savannah, GA		Tacoma, WA
Wilmington, NC		
Fernandina Beach, FL		
St. Marys, GA		

[a] No ranking is implied in the port listing.

- Port access in terms of direct ocean access versus the use of rivers and inland waterways

- Compatibility with existing port operations

- Safeguards and security

Unless available information indicated otherwise, all 36 ports have been assumed to be adequate for ocean cargo vessels regarding port cargo handling facilities, channel depth, and vessel turning and maneuvering areas.

The approach to evaluating transportation risk using the HIGHWAY 3.0 (Cashwell 1989) and RADTRAN 4.0 (Neuhauser 1989) computer codes has been described in Appendix A. Details on the rationale used by DOE in identifying alternatives ports of entry for consideration and their evaluation in selecting a preferred alternative are presented in Appendix B.

The results of the evaluation of alternative ports of entry presented in Appendix B concluded:

- The transportation risks and relative risks of all the alternatives considered were found to be small, with the risk to an individual of the public less than 10^{-7} (probability of fatality). The risks were dominated by the contributions of highway traffic fatalities and incident-free worker radiation exposure, rather than by accidents involving the release of Pu-238 fuel.

- The contribution of port accidents to the total risk of any given alternative was found to be small, approximately 10 percent. Thus, port population density does not become a discriminating factor in the quantification of risk. Although it might be perceived that a port with a low population density would reduce the risk, it does not do so in a significant manner.

Based on these results, DOE concluded that although selecting a port of entry using a minimum-risk approach is desirable when possible, it offered no clear advantages given that the total risks and relative risks of all the alternatives considered are small. This is especially true when the other evaluative criteria factors identified previously are taken into account. Based on these considerations, initial screening conclusions regarding the port of entry groups along the three coasts were as follows.

- For transportation to SRS, ports along the Atlantic Coast are preferable because they minimize transportation distance and risk compared to ports on the Gulf and Pacific Coasts.

- For transport to LANL, since the differences in transportation risks for ports along each of the three coasts are not significantly different (within a factor of 1.6), transportation distance becomes a discriminating factor. Generally, for exclusive use per unit distance travelled, ocean transport is more costly, and requires more time, people, and fuel than highway transport. A related consideration is that minimizing ocean transport distance also minimizes the risk of loss of cargo at sea in case of an accident. Due to the significantly longer ocean transport distances involved, the Pacific coast ports are less preferable than the Atlantic and Gulf Coast ports. For the same reason, but to a lesser degree, the Gulf Coast ports are less preferable than the Atlantic Coast ports.

As an added consideration in transport to LANL, based on the information presented in Appendix A, accident rates in the Gulf of Mexico are approximately twice those in the Atlantic. Thus, this is another reason for preferring Atlantic coast ports to Gulf coast ports for shipment to LANL.

Given that Atlantic coast ports in general were found to be preferable for shipments to both SRS and LANL to those on the Gulf and Pacific coasts, a second tier screening of Atlantic coast ports based on the evaluative criteria identified above resulted in the selection of Hampton Roads, VA as the preferred port of entry for the proposed action. The principle reasons for this selection are as follows:

- Differences in relative risk among the alternative ports of entry along the Atlantic coast were found to be small (within factors of 3.0 and 1.2 for SRS and LANL, respectively).

- Hampton Roads, VA has a number of commercial and U.S. Naval port facilities that could be used, thus maximizing DOE's flexibility in the required port activities under the proposed action.

- Hampton Roads has a full time port risk management staff and is experienced in handling cargo vessels importing foreign radioactive material, such as spent fuel (DOE1991b).

- The presence of the U.S. Naval port facilities would increase safety and help to assure the secure transfer of cargo from the Russian vessel to the SSTs in preparation for highway transport. In addition the emergency response capabilities and assets available at those port facilities would be advantageous in the event of an accident.

When DOE considered the commercial and U.S. Naval port facilities in the Hampton Roads area in light of the above conclusions, the Norfolk Naval Base was selected as the preferred port facility. Besides meeting basic criteria, it also would provide enhanced safeguards and security during the transfer operations of the Pu-238 fuel cargo from the Russian vessel to the SSTs. Representatives of the U.S. Navy have stated that the proposed action would be more compatible with exiting operations at the Norfolk Naval Base than with operations at other U.S. Naval port facilities in the area.

3.0 REFERENCE DESIGN INFORMATION

This section presents reference design information to provide a basis for the analysis of the environmental consequences of the proposed action.

3.1 CHARACTERISTICS OF PU-238 FUEL

In selecting a radioisotope for use in space applications, DOE conducted a screening process of potentially usable radioisotopes. Various factors, such as specific power, half-life, availability, gamma and neutron radiation, radiation hazard, and chemical form were considered, with Pu-238 in a dioxide form selected for the following reasons:

- High-specific thermal power, resulting from alpha decay with high-specific activity
- Safe with respect to nuclear criticality under all conditions of use
- 87.8 year half-life, providing a long-term source of power
- Low vaporization potential of the chemical form (dioxide) in fire environments
- Insolubility of the chemical form (dioxide), reducing its mobility in the environment, if released
- Low gamma-radiation level and acceptable neutron emission level

The Pu-238 fuel form intended for purchase from Russia is a plutonium dioxide powder containing about 85 percent by weight of Pu-238 dioxide. Each 5 kg shipment of Pu-238 (isotope mass) corresponds to 6.67 kg of plutonium dioxide. The bulk density of the powder is approximately 3.5 grams per cubic centimeter with a specific activity of 12.6 Curies per gram and a specific thermal power of 0.42 Watts per gram.

3.2 TRANSPORTATION GUIDELINES AND REQUIREMENTS

The containers to be used to ship the Pu-238 fuel must meet the transportation and safety requirements of U.S. and the Russia in accordance with international agreements. The protection of the public and transport workers from hazards associated with the shipment of the Pu-238 fuel, classed as special nuclear material, is achieved by a combination of limitations on the contents, the package design, and the method of shipment, as discussed below.

The International Atomic Energy Agency (IAEA), an agency of the United Nations, establishes the international standards for the rules governing radioactive material transportation throughout the world (IAEA 1985). The emphasis of the IAEA radioactive material transport standards is on ensuring packaging integrity. The packaging must be designed to protect against a release of material even in a severe accident. The packaging must be shown to survive a hypothetical accident sequence that includes impact, crush, puncture, fire, and water immersion. The level of protection is defined by the nature of the contents. These standards 1) address safety for the control of radiation hazards to persons, property, and the environment; and 2) stress the shipper's contribution to safety.

Both the U.S. and Russia are members of the IAEA, and by agreement, follow the IAEA standards regarding the packaging and shipment of radioactive materials. Therefore, U.S. and Russian regulations for the packaging and shipment of radioactive materials are consistent with the IAEA standards. Within the U.S., all aspects of transportation of these materials are regulated at the Federal level by the U.S. Department of Transportation (DOT). In addition, certain aspects, such as limitations on gross weight of trucks, are regulated by individual States.

A package shipped by highway in exclusive-use closed transport vehicles may not exceed radiation levels as provided in 49 CFR 173. This includes a limit of 2 mrem per hour at all normal crew positions in the vehicle. However, this provision does not apply when the vehicle crew personnel are operating under a radiation protection program and wear radiation exposure monitoring devices, as will be the case for transportation activities under the proposed action.

The type of radioisotope and quantity represented by the Pu-238 fuel that is the subject of this EA result in it being classed as special nuclear material, and it must be packaged and shipped in accordance with IAEA standards, and U.S. and Russian regulations applicable to Type B packages. Type B packages must survive certain severe hypothetical accident conditions, as defined in 10 CFR 71.73, that demonstrate resistance to impact, crush, puncture, fire, and water immersion. Packaging designs that meet the Type B performance criteria under both international standards and U.S. regulations are considered by DOT, DOE, and the U.S. Nuclear Regulatory Commission (NRC) to provide adequate protection of the public and operating personnel in the event of a transportation accident.

A Safety Analysis Report for Packaging (SARP) must be prepared for new shipping package designed, developed, and fabricated for offsite shipments of special nuclear material by DOE. Approval of the SARP results in issuance of a Certificate of Compliance for the packaging and its use. Once certified by DOE, a Certificate of Competent Authority is obtained from DOT to allow the package to be used for international shipments.

Radioactive material being imported by the U.S. may be offered and accepted for transport when packages are prepared for shipment in accordance with IAEA standards and U.S. regulations (10 CFR 71, 49 CFR 173, and DOE Orders). Inspection and enforcement activities by the U.S. Coast Guard (USCG) are carried out both in port and on ships operating in navigable waters of the U.S. Prior notification for all vessels and special notification requirements for this type of cargo are required by the USCG.

3.3 DESCRIPTION OF U.S. SHIPPING PACKAGES

Shipping packages provided by the U.S. will be used in the shipment of the subject Pu-238 dioxide within Russia, by ship, and within the U.S. from the port of entry to either SRS or LANL. The Mound 1 Kilowatt Thermal (KW) Package, designed by EG&G Mound Applied Technologies, Inc., will be used for the proposed shipments.

The Mound 1 KW Package was designed to comply with the regulations that govern the transport of Type B quantities of Fissile Class I plutonium heat-source material. The package was evaluated analytically and tested to determine its compliance with the applicable regulations for Type B certification. This means that two containment levels exist within the package, which was analyzed and tested to meet the design basis accident conditions and still maintain containment. A SARP has been prepared for the Mound 1 KW Package, containing results of evaluations and tests that demonstrate the package's compliance with applicable regulations of 10 CFR 71 regarding the general standards for normal conditions of transport and the standards for hypothetical accident conditions (EG&G 1993). The SARP has been approved by DOE, and both DOE and DOT certifications, indicating that the Mound 1 KW Package meets the criteria cited in Section 3.2, have been received.

The design specifications for the Mound 1 KW package allow for a maximum of 1.04 kg of Pu-238 dioxide per package. The Russian Pu-238 dioxide powder will be contained in welded, stainless steel product cans which will then be placed doubly-contained (inside primary and secondary stainless-steel containers) in the Mound 1 KW Package. Due to differences in product can loading, up to 8 Mound 1 KW Packages will be required to accommodate each 5 kg (Pu-238 isotope mass) shipment. Two Safe Secure Trailers (SSTs) will be required in the highway shipment of each 5 kg purchase, with the packages distributed between the two SSTs.

3.4 RUSSIAN TRANSPORTATION ACTIVITIES

The Pu-238 fuel will be placed in product cans at the Russian Federation's Mayak production facility at Chelyabinsk, Russia, and then into the Mound 1 KW Packages. The Mound 1 KW packages will then be placed inside International Shipping Organization (ISO) containers which will be locked and sealed with tamper indicating devices. The ISO containers will then be transported by rail to St. Petersburg from Chelyabinsk. At the dock in St. Petersburg the ISO containers will be loaded by crane onto the Russian cargo vessel. The material will then proceed by ship, non-stop, to a U.S. port. The preferred port of entry is Hampton Roads, VA, the rationale for which is presented in Section 2.2.2 and Appendix B.

3.5 U. S. TRANSPORTATION ACTIVITIES

Upon arrival of the Russian cargo vessel at Hampton Roads port facilities, the ISO container seals will be inspected and an exterior radiation survey conducted. The ISO containers with the Mound 1 KW Packages inside will be off-loaded by crane onto the dock. The ISO containers will be moved to a designated area where the Mound 1 KW Packages will then be transferred by forklift to SSTs prior to highway transport to LANL or SRS. The transfer operation from the cargo vessel to the SSTs will be conducted by DOE and DOE contractor personnel. All activities and personnel radiation exposure will be monitored in accordance with established DOE procedures.

Shipment of the material under the proposed action from the port of entry to the SRS or LANL by SSTs will be made by DOE Albuquerque Operation Office's Transportation Safeguards Division (TSD). These shipments will be in accordance with DOT regulations (49 CFR 171-179) and DOE Orders. The safety design features of the Type B shipping package, represented by the Mound 1 KW Package, coupled with the impact protection and thermal shielding (in case of fire) of the SST, ensure that no release of Pu-238 could occur in all but the most severe, low probability accidents.

The DOE-TSD safety standards effectively minimize the probability of accidents. DOE-TSD has never experienced a radiological accident in several million miles of highway transport and the DOE-TSD safety record is several times better than that of the commercial trucking industry. Shipments of material are constantly monitored and tracked to ensure prompt attention and proper notification of authorities in the event of an accident. If an accident should occur, drivers are trained to make a preliminary assessment of the situation. If necessary, radiological assistance teams are readily available to help mitigate the consequences of the accident.

3.6 SRS PROCESSING AND STORAGE

The U.S. specifications for the imported Pu-238 establish limits on chemical impurity levels necessary to ensure product quality, performance, and material compatibility for space mission applications. The initial 5 kg shipment is known to have a cerium level in excess of the U.S. specifications. However, subsequent shipments should meet U.S. specifications. Any such imported Pu-238 not meeting U.S. specifications will be processed through facilities at SRS to remove any impurities, although the proposed action includes provisions to process up to the entire imported amount (40 kg) should it be necessary. After processing, the Pu-238 would be stored at SRS. The SRS facilities required to process and store Pu-238 have been addressed in DOE/EA-0534 (DOE 1991c).

3.7 LANL HANDLING AND STORAGE

Any Pu-238 transported to LANL will be added to the Pu-238 inventory at LANL. No changes to physical structures will be required at LANL as part of this proposed action. The LANL facilities required to receive, handle, and store Pu-238 have been addressed in DOE/EA-0534 (DOE 1991c).

4.0 AFFECTED ENVIRONMENT

During the transportation sequence from point of origin in Russia to the U.S., and within the U.S. from the port of entry to either SRS or LANL, various environments could be affected by the proposed action. These potentially affected environments include the Russian land and port environments, the marine environment, the U.S. port locale, highway routes, LANL, and SRS. Each of these is discussed below in connection with the proposed action.

4.1 RUSSIAN AFFECTED ENVIRONMENT

Russia is the cooperating partner in the proposed action with the U.S. As such, Russia exercises its sovereign authority to regulate activities conducted in its nuclear facilities and the handling of nuclear materials within its territorial boundaries. Thus, the Russian environment that could be affected by this proposed action, including Pu-238 facility sites, land transportation routes, and loading port, are not addressed in this EA.

4.2 OCEAN ENVIRONMENT

The ship transporting the Pu-238 fuel from St. Petersburg, Russia, to the preferred port of entry (Hampton Roads, VA) would use normal shipping lanes through the Baltic Sea, North Sea, and Atlantic Ocean. The ocean transport distance from St. Petersburg to the preferred port of entry (Hampton Roads, VA) is estimated to be 8,500 kilometers (km).

4.3 U.S. AFFECTED ENVIRONMENT

4.3.1 Port of Entry

The preferred port of entry for the proposed action is Hampton Roads, VA, located at the mouths of the James and Elizabeth Rivers at the base of the Chesapeake Bay. Hampton Roads consists of several civilian and U.S. Naval port facilities. The majority of research reactor spent fuel shipments to the U.S. by sea has been shipped through the Hampton Roads marine terminals. Hamptons Roads has full-time risk management staff and several years of experience handling radioactive materials cargo, such as spent fuel casks.

Within Hampton Roads, the Norfolk Naval Base is the preferred port facility. The population density of Norfolk, VA, where the largest port facilities are located in the Hampton Roads area, is 2,000 persons per square km (USDC, 1988). This value has been used in the analysis.

4.3.2 Land Transportation Routes

Historically, all shipments of Pu-238 dioxide in the U.S. have been made by truck. Because of their high and uniform levels of engineering and safety, the Interstate Highways have been identified by DOT as preferred routes for transport of highway-route-controlled quantities of radioactive materials. The highway transport routes of interest are those from Hampton Roads, VA to SRS or LANL. The HIGHWAY 3.0 computer code (Cashwell, 1989), described in Appendix A, Section A.1, was used to determine the distances travelled in areas of urban, suburban, and rural population density zones for these highway routes, as summarized in Table 4-1.

Table 4-1
Highway Transportation Distances from Preferred Port of Entry
(Hampton Roads. VA)

Route To	Distance, km			
	Rural[a]	Suburban[b]	Urban[c]	Total
SRS	534	268	6	808
LANL	2,503	696	52	3,251

[a] Averages 6 persons per square km
[b] Averages 719 persons per square km
[c] Averages 3861 persons per square km

4.3.3 SRS

Processing of any imported Pu-238 not meeting U.S. specifications would occur at SRS. As previously discussed, the Pu-238 would be stored at SRS after processing. Existing SRS facilities for processing Pu-238 consist of the 221-HB-Line located in H-Area Canyon Building, including the Scrap Recovery Facility and the Plutonium Oxide Facility. The Storage Vault Facility would be used to store the Pu-238 after processing. No new facilities would be required. The SRS encompasses approximately 800 square km in southwestern South Carolina. It borders the Savannah River for about 27 km. The SRS has a temperate climate with mild winters and long summers. SRS facilities include production reactors, separations facilities, and support facilities for the production of Federal nuclear materials. Approximately 550,000 persons live within an 80-km radius of SRS that includes portions of South Carolina and Georgia. Details of the affected environment at SRS in the context of Pu-238 processing have been addressed in DOE/EA-0534 (DOE 1991c) which is incorporated by reference into this EA.

4.3.4 LANL

Handling and storage of Pu-238 fuel that meets U.S. specifications and therefore does not have to be processed at SRS would occur at LANL. Existing facilities at LANL for handling Pu-238 consist of the Plutonium Handling Facility Building 4 (PF-4) at Technical Area 55 (TA-55). No new facilities would be required. The LANL site encompasses approximately 111 square km in north-central New Mexico. It is located on the Pajarito Plateau, a series of mesas and canyons, at an elevation of about 2,200 meters above sea level. LANL has a semi-arid, temperate mountain climate. LANL includes facilities related to Federal nuclear weapons research and development and other scientific research. An estimated 203,000 persons live within an 80-km radius of the LANL site. Details of the affected environment at LANL in the context of Pu-238 handling have been addressed in DOE/EA-0534 (DOE 1991c) which is incorporated by reference into this EA.

5.0 ENVIRONMENTAL CONSEQUENCES

This section describes the environmental consequences of the proposed action resulting from normal operations and potential accidents. The focus is on the effects of the proposed action on the ocean environment (global commons) and the U.S. affected environment (port of entry, highway transportation routes, LANL, and SRS). The environmental consequences presented are bounding in that the results reflect the transport of 40 kg of imported Pu-238 from the preferred port-of-entry (Hampton Roads, VA) to either SRS or LANL. The results presented in this section are applicable to all the port facilities (both civilian and U.S. Naval) within Hampton Roads, since any differences would be well within the uncertainties of the analysis. As noted in Section 4.0, Russia exercises its sovereign authority to regulate activities conducted in its nuclear facilities and the handling of nuclear materials within its territorial boundaries. For this reason, the environmental consequences of the proposed action on the Russian affected environment are not discussed in this EA.

5.1 NORMAL OPERATION IMPACTS OF PROPOSED ACTION

5.1.1 Transport (Ocean and Highway)

Under normal handling and transport conditions the hazard posed by the Pu-238 fuel would be external exposure to gamma and neutron radiation to package handlers, transport crew, and the general public. These radiation doses would be within the limits specified by the regulations (See Section 3.2). The radiological consequences of the import and incident-free transportation were evaluated using the RADTRAN 4.0 code (Neuhauser, 1989), as described in Appendix A, Section A.4. The results are summarized in Table 5-1. The incident-free transportation risks are estimated to be 1.5×10^{-3} and 3.6×10^{-3} latent cancer fatalities for transport to SRS and LANL, respectively. A breakdown of the collective dose components in terms of exposure groups is presented in Table 5-2.

5.1.2 SRS

The environmental consequences at SRS of processing the entire, existing U.S. Pu-238 inventory (64 kg, current nominal) have been addressed in DOE/EA-0534 (DOE 1991c). These consequences consisted of increasing the offsite doses due to SRS operations by less than 1 percent. The impacts of processing up to an additional 40 kg of Pu-238 under this proposed action would increase the 1 percent by a factor of 0.63, for a cumulative increase of about 2 percent.

The volumes of transuranic (TRU) waste and low-level radioactive waste (LLW) to be generated at SRS as a result of the action addressed in DOE/EA-0534 was estimated to be 94 and 396 cubic meters per year, respectively, representing about 8 and 1.3 percent of the TRU and LLW, respectively, generated at SRS on an annual basis in past years. Processing up to an additional 40 kg of Pu-238 under this proposed action would increase these impacts by a factor of 0.63, corresponding to an additional increase in TRU and LLW volumes of about 59 and 250 cubic meters annually for the processing period.

Table 5-1

Incident Free Transportation Risks for Preferred Port of Entry (Hampton Roads, VA)[a]

Transportation	Collective Dose, person-rem[b]	Maximum Individual Dose, rem[c]	Health Effects Risks	
			Radiation[d]	Non-Radiation
Ocean transport	8.68×10^{-1}	-	4.34×10^{-4}	-
Highway transport				
Port to SRS	2.16×10^{0}	4.21×10^{-6}	1.08×10^{-3}	-
Port to LANL	6.29×10^{0}	4.21×10^{-6}	3.14×10^{-3}	-

[a] All results in terms of risk (probability times consequence) and are bounding, representing eight shipments of Pu-238 totalling 40 kg (isotope mass) to each site (SRS and LANL).
[b] Collective effective dose equivalent as defined in ICRP-30 (ICRP 1979).
[c] Maximally exposed individual of the public.
[d] Radiation health effects determined using a health effects estimator of 5×10^{-4} latent cancer fatalities per person-rem for low doses (applied to incident-free conditions) and 10×10^{-4} for high doses (applied to accident conditions) based on ICRP (1990).

Table 5-2

Collective Dose Components for Incident-Free Transportation

Transport Type	Component	Collective Dose, person-rem	
		SRS	LANL
Ocean	Crew	7.10×10^{-2}	7.10×10^{-2}
	Handlers	7.04×10^{-1}	7.04×10^{-1}
	Stops	5.91×10^{-2}	5.91×10^{-2}
	Storage	3.39×10^{-2}	3.39×10^{-2}
	Subtotal	8.68×10^{-1}	8.68×10^{-1}
Highway	Crew	3.14×10^{-1}	1.16×10^{0}
	Handlers	7.08×10^{-1}	7.08×10^{-1}
	Off-Link[a]	3.20×10^{-2}	8.88×10^{-2}
	On-Link[b]	1.80×10^{-1}	5.85×10^{-1}
	Stops	9.29×10^{-1}	3.75×10^{0}
	Subtotal	2.16×10^{0}	6.29×10^{0}

[a] General public along the roadsides.
[b] Passengers in other vehicles sharing the highway.

5.1.3 LANL

The environmental consequences at LANL of handling the entire, existing U.S. Pu-238 inventory (64 kg, current nominal) have been addressed in DOE/EA-0534 (DOE 1991c). These consequences consisted of increasing the offsite doses due to LANL operations by less than 0.00002 percent. The impacts of handling up to an additional 40 kg of Pu-238 under this proposed action would increase the 0.00002 percent by a factor of 0.63, for a cumulative increase of about 0.00003 percent.

The TRU waste volume at LANL resulting from the action addressed in DOE/EA-0534 was estimated to be 25 drums per year, representing about 3.5 percent of the TRU waste generated annually at LANL. The handling and storage of up to an additional 40 kg Pu-238 under this proposed action would increase the TRU waste volume by approximately 15 drums.

5.2 ACCIDENT IMPACTS OF PROPOSED ACTION

5.2.1 Ocean Transport

Since the proposed action involves ocean transport, DOE also considered the environmental consequences of this action on the global commons in accordance with Executive Order 12114 and DOE Guidelines for Compliance with Executive Order 12114.

The probabilities of marine accidents and their severity have been summarized in Appendix A, Section A.2. Due to the design safety features of the Mound 1 KW Package and the manner in which it would be handled and stowed onboard ship, only the most severe ship accident could result in a release of radioactive material. This accident would consist of a severe collision coupled with a severe fire in the port. The probability of this accident was estimated to be in the range of 7.8×10^{-9} to 1.1×10^{-8} per port call. The radiological risk (probability times consequence) of this accident assuming it occurred in port was evaluated using the RADTRAN 4.0 code, as described in Appendix A, Section A.4. The resulting risk was estimated to be 2.4×10^{-4} latent cancer fatalities. This risk estimate represents the total for all ocean shipments of Pu-238 fuel (eight shipments of 5 kg each) under the proposed action. The population density of Norfolk, VA of 2,000 persons per square kilometer, the highest in the Hampton Roads area, was used for this calculation.

For accidents in a port, the immersion environment is rather benign since port waters average less than 200 meters in depth. Present day salvage techniques allow for recovery of packages at depths of up to 200 meters from the sea bed (DOE 1991b). Should the Mound 1 KW Package be lost at sea in depths greater than 200 meters, long-term containment of the fuel would be expected due to the low corrosion rates of the stainless-steel used in the package's construction. Should the package containment be breached, studies of the behavior of Pu-238 heat source components in the ocean environment indicate that the heat of radioactive decay promotes encrustation by mineral deposits from the seawater, further reducing the possibility of release (NASA 1989 and 1990). Even if a release of Pu-238 should occur, the oxide nature of the fuel results in a very low dissolution rate and the aquatic chemistry of plutonium is such that it preferentially binds with the sediment rather than remaining dissolved.

5.2.2 Highway Transport

The potential for highway accidents during the transport by SST has been evaluated in Appendix A, Section A.3. Accident assumptions are included for eight categories of accidents depending on their severity. Category I is the least severe and most frequent category of accident, whereas category VIII accidents are very severe but very infrequent. Radioactive material could be released from the SST in only the most severe accident (category VIII). The category VIII accident is characterized by a combination of crush forces and fire duration that are expected in only the rarest accident. The probability of accident severity category VIII for each highway transport route considered, accounting for the distance travelled in each population density zone, is 2.1×10^{-7} for shipment to SRS and 8.3×10^{-7} for shipment to LANL. These represent bounding probabilities for transport of 40 kg of Pu-238 to either site.

The radiological risks of category VIII highway transport accidents under the proposed action were evaluated using the RADTRAN 4.0 code, as described in Appendix A, Section A.4. Since the conditions associated with the extremely rare and severe Category VIII accidents exceed those required for qualification of the Mound 1 KW Package, the fraction of Pu-238 released from package containment in such an accident was taken to be 0.1 based on the values adopted in NUREG-0170 (NRC 1977). DOE considers this release fraction to be conservative.

The resulting estimated accident risks, in terms of latent cancer fatalities and traffic fatalities (resulting from nonradiological accidents), are presented in Table 5-3. The transportation accident risks are 8.6×10^{-4} and 3.6×10^{-3} fatalities for transport (ocean and highway) to SRS and LANL, respectively. In both cases the non-radiological traffic fatalities are the highest contributor to accident risk.

Type B containers have been transported in SSTs for over 15 years. DOE's operational experience with shipments of this type is extensive, and there have been no accidents resulting in radioactive releases, nor have there been any traffic fatalities. Thus, the above probability and risk estimates of SST transport are likely overstated.

5.2.3 SRS

The risk of postulated accidents at SRS resulting from processing of the entire existing U.S. Pu-238 inventory (64 kg, current nominal) have been addressed in DOE/EA-0534 (DOE 1991c). The largest contributor to risk was found to be abnormal low-energy events at the Scrap Recovery Facility involving process equipment leaks, transfer errors, overflows, and spills with a combined frequency of 0.21 per year. These accidents could release 1.7×10^{-2} curies to the stack with a resulting collective dose risk (onsite and off-site) of 79 person-rem per year. The resulting risk contribution would be 1.7×10^{-2} fatalities per year during the processing period.

The risk of accidents from processing up to an additional 40 kg (5 kg nominal, up to a maximum of 40 kg) at SRS under this proposed action would increase this risk contribution by a factor of up to 0.63 corresponding to 2.7×10^{-2} fatalities per year during the processing period.

5.2.4 LANL

The risk of postulated accidents at LANL resulting from handling the entire existing U.S. Pu-238 inventory (64 kg, current nominal) has been addressed in DOE/EA-0534 (DOE 1991c). The

Table 5-3

Transportation Accident Risks for Preferred Port of Entry (Hampton Roads, VA)[a]

Transportation	Collective Dose, person-rem[b]	Maximum Individual Dose, rem[c]	Health Effects	
			Radiation[d]	Non-Radiation[e]
Ocean transport[f]	2.42×10^{-1}	[g]	2.42×10^{-4}	-
Highway transport				
Port to SRS	6.75×10^{-2}	[g]	6.75×10^{-5}	5.54×10^{-4}
Port to LANL	2.02×10^{-1}	[g]	2.02×10^{-4}	3.20×10^{-3}

[a] All results in terms of risk (probability times consequence) and are bounding, representing eight 5 kg shipments of Pu-238 totalling 40 kg (isotope mass) to each site (SRS and LANL).

[b] Collective effective dose equivalent as defined in ICRP-30 (ICRP 1979).

[c] Maximally exposed individual of the public.

[d] Radiation health effects determined using a health effects estimator of 5.0×10^{-4} latent cancer fatalities per person-rem for low doses (applied to incident-free conditions) and 10×10^{-4} for high doses (applied to accident conditions) based on ICRP (1990).

[e] Nonradiological accident fatalities resulting from mechanical injury.

[f] Resulting from severe accident in port.

[g] Maximum individual dose risk is not reported for accidents due to large uncertainties in exposure scenarios for persons in the accident vicinity.

largest contributor to risk was found to be an accident scenario involving a fire in one of the glove boxes, with a probability of 10^{-4} per year or less. Using conservative assumptions the collective dose to the offsite population would be 4.7 person-rem. The corresponding risk contribution would be 4.7×10^{-7} fatalities per year. The risk of accidents from handling up to an additional 40 kg at LANL under this proposed action would increase this risk contribution by a factor of up to 0.63, corresponding to 7.5×10^{-7} fatalities per year.

5.3 CUMULATIVE TRANSPORTATION IMPACTS

The port facilities at Hampton Roads, VA have been used in the past to receive and handle foreign research reactor spent fuel for subsequent highway transport to SRS (DOE 1991b). Since 1978 DOE has received over 360 foreign spent fuel shipments at SRS through Hampton Roads port facilities. There have been no releases or environmentally significant impacts from any of these past shipments. The potential consequences of importing an additional 48 shipments of spent fuel have been addressed in DOE/EA-0515 (DOE 1991b). The transportation risks of the additional 48 shipments under incident-free and accident conditions were estimated to be 6.9×10^{-2} fatalities, with 99 percent due to non-radiological traffic fatalities along highways and less than 1 percent due to port activities. Assuming the transportation risks of the previous 360 shipments were similar to the additional 48, then the total risk of the 408 shipments (past and additional future) are estimated to be approximately 0.79 fatalities. The transportation risks (incident-free and accident risks combined) of the current proposed action are estimated to be 2.4×10^{-3} to 7.2×10^{-3} for shipments to SRS or LANL, respectively, as summarized in Table 5-4. When combined with the transportation risks of the past and future potential additional spent fuel shipments through Hampton Roads, the cumulative transportation risks would increase less than 1 percent to about 0.80 fatalities. Again, note that most of this risk has already been incurred with the previous 360 spent fuel shipments with no accident consequences.

DOE is also considering import of other foreign radioactive materials in the future (e.g., highly enriched uranium, low-enriched uranium, uranium hexafluoride, and other plutonium isotopes). These possible actions would be consistent with important foreign relations and national security objectives of the U.S. and the provisions of the Atomic Energy Act of 1954, as amended, and the Nuclear Non-Proliferation Act. The acceptance of such radioactive materials by the U.S. would serve nonproliferation interests by removing potential nuclear weapons useable material from abroad. Should DOE decide to seriously pursue such future import actions, appropriate documentation would be prepared for such actions in accordance with NEPA requirements. Future cumulative impacts arising from such actions would be addressed in those NEPA documents.

Table 5-4

Total Transportation Accident Risks for Preferred Port of Entry (Hampton Roads, VA)[a]

Risk Contributor	Risk, Fatalities	
	SRS	LANL
Incident-free transport		
Ocean	4.34×10^{-4}	4.34×10^{-4}
Highway	1.08×10^{-3}	3.14×10^{-3}
Subtotal	1.51×10^{-3}	3.57×10^{-3}
Accidents		
Ocean	2.42×10^{-4}	2.42×10^{-4}
Highway		
Radiological	6.75×10^{-5}	2.02×10^{-4}
Non-radiological	5.54×10^{-4}	3.20×10^{-3}
Subtotal	8.65×10^{-4}	3.64×10^{-3}
Total[b]	2.38×10^{-3}	7.22×10^{-3}

[a] All results in terms of risk (probability times consequence) and are bounding, representing eight 5 kg shipments of Pu-238 totalling 40 kg (isotope mass) to each site (SRS and LANL).

[b] Differences in total and sum of subtotals is due to roundoff.

6.0 AGENCIES AND PERSONNEL CONSULTED

This document was prepared using information provided by and discussed with the Russian Federation Ministry of Atomic Energy and the U.S. Navy.

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APPENDIX A

METHODOLOGY USED IN THE ENVIRONMENTAL CONSEQUENCE ANALYSIS

APPENDIX A

METHODOLOGY USED IN THE ENVIRONMENTAL CONSEQUENCE ANALYSIS

This appendix describes the methodology used in evaluating the environmental consequences of transporting Pu-238 fuel under normal and accident conditions under the proposed action. The focus is on potential accidents that could release the Pu-238 into the environment during handling and transport.

A.1 OVERVIEW OF METHODOLOGY

The radiological impacts of transporting radioactive materials include radiation doses and associated health effects due to external radiation from packages during normal transport and radioactive releases under accident conditions. Transportation accident risk may be defined as the consequences of an accident multiplied by the probability of that accident. The probabilities of occurrence of various accident severity categories are determined by the base accident rate for the mode and the conditional probability for the category. Accident severity is a function of the magnitudes of the impact, puncture, and thermal environments to which a package may be subjected during an accident. The base rate is multiplied by the conditional probability for a severity category to generate the overall accident probability of that severity category.

In the accident risk analysis, the consequences are determined based on the radionuclide contents of the material being shipped; the behavior of the package in each accident severity category; the dispersal of radioactive material that may be released from the package; and the doses to persons from the radioactive material. After the component risks are generated, they are summed and multiplied by a dose-conversion factor to estimate the health effects risk.

The RADTRAN computer code (currently version 4.0) developed by Sandia National Laboratories (Neuhauser, 1989) is commonly used to calculate the risks associated with the transport of radioactive materials by various modes, including truck and ship. The radiological consequences considered include those during incident-free transportation (due to external radiation) and under accident conditions (involving a release of radioactive materials to the environment). The exposed population groups considered include the crew, package handlers, and the general public along and off the transport links.

During incident-free transport, the radiological consequences will depend in part on the Transport Index (TI) value of the package and the surrounding population densities. The TI is a dose-rate index defined as the dose rate in millirem per hour at 1 meter from the package surface.

Under accident conditions, radiological consequences are calculated by assigning release fractions to each accident severity category for each chemically and physically distinct type of radionuclide. The release fraction is defined as that fraction of the radionuclide in the package that could be released in a given severity of accident. Release fractions vary by package type. Most solid materials are relatively nondispersible and would be difficult to release in particulate form. Aerosol (airborne dispersed) and respirable aerosol fractions are assigned by material dispersibility category that describe the physical form of the material.

In evaluating the radiological consequences, RADTRAN 4.0 uses an atmospheric transport and dispersion model for material dispersed from an accident, and considers radiation doses resulting from the direct inhalation, resuspension, cloudshine, groundshine, and ingestion pathways.

For highway transport, three population-density zones are considered (rural, suburban, and urban). Specific locale population densities for the proposed action and alternatives were used in determing the fraction of highway distances travelled in each zone. The accident probability rates are population zone-specific due to differences in average speed, traffic density, and other factors in rural, suburban, and urban areas. The accident rates used are from DOT data for the entire commercial shipping industry, and are based on millions of total vehicle-kilometers of travel.

Representative interstate highway routes from each potential origin to each potential destination for use in RADTRAN 4.0 are generated by the HIGHWAY 3.0 routing network code, which also give fractions of travel in rural, suburban, and urban population density zones and total one-way distance (Cashwell 1989). The HIGHWAY 3.0 routing network includes the Interstate Highway system, state-designated alternate routes, and access routes to various DOE facilities. Because of their high and uniform levels of engineering and safety, the Interstate Highways have been identified by the DOT as the preferred routes for transport of highway-route-controlled quantities of radioactive materials; where available, urban beltways and bypasses are used.

To calculate total transport risk, the risk per kilometer per shipment is multiplied by the number of kilometers a shipment travels in the appropriate population density zone and by the number of shipments of that type; these products are then summed.

Similar calculations are performed for non-radiological unit-risk factors (e.g., risk of fatality from mechanical injury) to determine total nonradiological risks. Note that for these risks the two-way travel distance is used because, while radiological risk may be incurred only for a shipment containing radioactive material, nonradiological risks are equally likely when the transport vehicle is traveling empty or loaded.

A.2 MARITIME ACCIDENT PROBABILITIES AND ENVIRONMENTS

A.2.1 Maritime Accident Probabilities

Hypothetical maritime accidents can be described in a sequence as the vessel travels from the open ocean to dockside. Accidents of all severities on the open seas occur with a frequency of from 2.9×10^{-4} to 5.8×10^{-4} accidents per trip, with the lowest value being for the Atlantic Ocean and the highest value for the Gulf of Mexico. Historically, about 54 percent of all accidents in port and on the open seas are collisions (Warwick 1976). For port accidents, only about 2.5 percent involve fires (OR 1979). The remaining accidents are groundings and other non-collision accidents (Warwick 1976). Since vessels generally move on the open seas with higher speeds than in ports, collision accidents on the open seas tend to be more severe. As a vessel nears port, it enters more congested waters and speed decreases, but accident frequencies increase because of the increased ship traffic and relative proximity of one vessel to another.

The probabilities of marine accidents and their severity have been evaluated (OR 1979) and summarized in DOE/EA-0515 (DOE 1991b). This evaluation indicated that approximately 73 percent of the marine accidents reported to the U.S. Coast Guard are in inland waters. The remaining 27 percent were on the open seas. Based on collision accident frequencies in inland waters, the probabilities of various collision severity levels determined in DOE/EA-0515 (DOE 1991b) are summarized in Table A-1.

Table A-1

Probabilities for Accidents in Ports

Accident Environments in Increasing Severity Level (Net Additive)	Probability, per port call
Immersion	4.0×10^{-4}
Any collision	2.5×10^{-3}
Severe collision	1.8×10^{-4}
Severe collision impacting a given cargo hold	2.9×10^{-5}
Fire following a severe collision impacting a given cargo hold	7.8×10^{-9} to 1.1×10^{-8}

A review of actual transport experience during a 16 year period (1971 to 1985) of DOT record keeping through the Hazardous Material Incident (HMI) reporting system shows that no transport accidents in U.S. waters involving radioactive material have occurred for the water transport mode (DOE 1991b).

A.2.2 Maritime Accident Environments

A.2.2.1 Package Response to Immersion

For accidents in a port, the immersion environment is rather benign since port waters average less than 200 meters in depth. Present day salvage techniques allow for recovery of packages at depths of up to 200 meters from the sea bed (DOE 1991b). Should the Mound 1 KW Package be lost at sea in depths greater than 200 meters, long-term containment of the fuel would be expected due to the low corrosion rates of the stainless-steel used in its construction. Studies of the behavior of Pu-238 heat source components in the ocean environment indicate that the heat of radioactive decay promotes encrustation by mineral deposits from the seawater, further reducing the possibility of release (NASA 1989 and 1990). Even if a release of Pu-238 would occur, the oxide nature of the fuel results in a very low dissolution rate and the aquatic chemistry of plutonium is such that it preferentially binds with the sediment rather than remaining dissolved.

A.2.2.2 Package Response to Mechanical Forces

Collisions are among the most potentially severe accidents that occur in the region of a port. Although some groundings could be severe enough to tear the ship's hull structure and perhaps even cause flooding of some cargo compartments, groundings present less threat of mechanical damage than collisions.

In practice, for load management purposes, the packages are stowed toward the center line of cargo vessels. This practice also results in packages usually being located at least 8 meters away from the ship's hull. Past collisions in which a ship was struck broadside by a ship with a relatively rigid bow (e.g., an icebreaker) did not result in penetration that deep (8 meters) into the structure of the struck ship.

DOT regulations in 49 CFR 173 require that "each shipment of radioactive material shall be secured in order to prevent shifting during normal transportation conditions." If a package secured by tiedowns were exposed to direct forces, then the tiedowns could either fail or hold. If they failed, then the package would most likely be pushed aside rather than absorb the energy of the collision.

A.2.2.3 Container Drops During Off-loading

Another category of accident that is not related to ship collisions is container drops during handling. In a study of one port that handled large amounts of containerized cargo, involving at least 750,000 moves annually, an estimated 1 to 2 containers were dropped per year (DOE 1991b). A move is defined as an operation in which a crane picks up a container, moves it, and disengages. This amounts to an historical probability of a container drop of about 2.7×10^{-6} per year.

The berths at ports consist of concrete aprons constructed on friction pilings (driven into the sediment or bedrock) or on tamped earth contained within sheet pilings. Both are relatively yielding surfaces, and the water or the deck of a ship are even more yielding than a dock surface.

A.2.2.4 Package Response to Fire

Packages of the type to be used to transport the Pu-238 fuel are designed and tested to survive the thermal load specified in the package certification performance criteria (i.e., the thermal load from a fully engulfing fire at 1475°F for 30 minutes) with no release of contents. Creep-stress rupture of the containers would begin to occur only after the package was exposed to 1475°F for much longer periods of time. The rupture event could release a small fraction of the fuel into the primary container cavity, but would relieve the pressure buildup. Thus, unless the package also sustained mechanical damage, a significant release into the primary containment of the package would be difficult to achieve by fire alone. Furthermore, a release to the primary containment vessel does not imply a release to the environment. In the latter case, fire alone is not a credible means of causing a release and any accident sequence that resulted in a release of contents must include exposure of the same package to mechanical forces great enough to cause failure (i.e., greater than in the certification tests). As a final note, the packages will be shipped inside ISO containers that will provide additional thermal (and mechanical) protection in case of an accident.

Fires are historically a small fraction (about 2.5 percent) of maritime accidents (OR 1979). Cargo ships are equipped with fire suppression equipment to handle most fires. Historical records regarding maritime accidents indicate that while some severe fires have occurred, they represent no more than 3 percent of all ship fires (OR 1979). Severe ship fires often involve flammable liquids and may burn for many hours or days or until the ship sinks, but fires of this type occur almost exclusively on ships carrying petroleum products (e.g., oil tankers). A cargo ship carrying the Pu-238 fuel could become involved in such a fire if it was involved in a collision with a tanker, the contents of which subsequently ignited.

Since stowage regulations require that no other hazardous or flammable material be stowed with radioactive materials, the largest potential on-board source of flammable material to sustain a major fire in a cargo ship carrying the Pu-238 fuel is the ship's fuel supply. Protection provided by the Mound 1 KW Packages and the ISO containers, and the separation of the cargo from the ship's fuel would be factors that would reduce the effects of a fire. In practice, mitigating measures such as flooding a hold with water could be used to prevent packages from experiencing excessive thermal loads.

A.3 HIGHWAY ACCIDENT PROBABILITIES AND ENVIRONMENTS

The average truck accident rate for the entire U.S. is 3.1 x 10^{-7} accidents per kilometer (km). The average rates for the three population density zones of interest in RADTRAN 4.0 are 1.37 x 10^{-7} per km for rural (average of 6 persons per square km), 3.00 x 10^{-6} per km for suburban (average of 719 persons per square km), and 1.60 x 10^{-5} per km for urban (average 3,861 persons per square km), respectively. These rates are for all reported combination truck accidents on interstate highways. The accident conditions for the various severity categories are described in NUREG-0170 (NRC 1977). Eight accident categories are designated with conditional probabilities developed for the severity categories for truck shipments, ranging in severity from the lowest (category I) to the highest (category VIII). A category VIII accident is characterized by a combination of crush forces and fire duration with severity conditions would be expected in only the rarest of accidents.

The probability of the very severe accident which would be required to result in a release of radioactive material carried by an SST would be lower than the same probability for the U.S. trucking industry as a whole. For example, SSTs do not operate in poor weather conditions. Restricting truck transport to good weather conditions reduces the overall truck accident rate by about 10 percent (NRC 1977). The accident resistance provided by the SST is significant. The high integrity of the trailer acts as an impact-force-reducing barrier and provides thermal protection. The thermal protection provided by the SST is such that the SST is capable of withstanding temperatures in excess of the regulatory test-fire temperature (1475°F) for periods exceeding the test duration of 30 minutes without significant elevation of internal temperature. When the additional thermal protection of the Type B package is considered, the Pu-238 fuel would not directly experience thermal loads characteristic of a category VI fire. The SST so effectively prevents either of these conditions from affecting the payload that a category VI accident would not result in any release of contents. Lesser accident categories (I through V) would also not result in a release of material to the environment.

The generic release fractions for each accident severity category are estimated in NUREG-0170 (NRC 1977) and indicate values of 0.01 and 0.1 for categories VII and VIII, respectively. The release fractions assigned to the Type B packaging in accident severity categories VII and VIII for the packaging itself must be modified to reflect the protection afforded a shipment by the SST. For an integral transport vehicle, such as the SST, NUREG-0170 indicates no release for category VII and a release fraction of 0.1 for category VIII, thus conservatively granting no protection credit to the SST in these extreme circumstances.

Given an accident, the conditional probability of a severity category VIII for each of the three population zones of interest in RADTRAN 4.0, are 1.13 x 10^{-4} for rural, 5.93 x 10^{-6} for suburban, and 9.94 x 10^{-7} for urban, respectively. No transport accident this severe (category VIII) has ever been recorded (DOE 1988). The total accident probability is determined by product of the population-zone specific base accident rate times the distance travelled in each population zone (in kilometers) and the conditional probability of severity category VIII in each population zone, summed over the population zones. When nonradiological accidents involving traffic fatalities are considered, the appropriate state-specific accident rates are used. Note that in determining the nonradiological accident rate, the round trip distance is used.

A.4 APPLICATION OF RADTRAN 4.0

The RADTRAN 4.0 computer code (Newhauser, 1989) described in Section A.1 has been applied to estimate the risks (probability times consequence) resulting from transportation under both incident-free and accident conditions. Information presented for ocean and highway transport in Sections A.2 and A.3, respectively, has been used as a basis for this analysis. The parameter inputs use in this analysis are presented below.

RADTRAN 4.0 inputs related to transport link distances, population densities, and accident probabilities are those as described in Sections A.2 and A.3 for ocean and highway transport, respectively. Parameters used that are specific to the Pu-238 fuel of interest are as follows:

- TI index: 11 (20 percent due to gammas and 80 percent due to neutrons) for a single fully loaded Mound 1 KW Package with 1.04 kg of Pu-238 dioxide, corresponding to 13,100 Curies.
- Packages per shipment: 8 nominal with 10,688 Curies of Pu-238 per package (total of 85,500 Curies per shipment)
- Fuel form: plutonium dioxide powder
- Release fraction: 0.1 for accident severity category VIII
- Aerosol (airborne dispersed) fraction: 0.8
- Aerosol respirable fraction: 0.005

Parameter values used for the ocean transport phase are as follows:

• Number of crewmen	10
• Distance from source to crew (meters)	61
• Number of handlings	2
• Stop time at dock per shipment (hr)	3
• Number of persons exposed while stopped	50
• Exposure distance while stopped (meters)	50
• Storage time on dock (hr) [Note: This is conservative in that no storage on the dock prior to the transfer to SSTs is anticipated]	24
• Exposure distance during storage (meters)	100
• Number of persons exposed during storage	20
• Cargo vessel speed during voyage (km/hr)	24.2

For the port accident scenario, a severe accident probability of 1.1×10^{-8} per shipment was used. The release quantity was estimated using the same assumptions identified above for Pu-238. The population density was taken as port-specific based on USDC (1988).

Parameter values used for the highway transport phase are as follows:

• Speed in rural population zone (km/hr)	88.6

Speed in suburban population zone (km/hr)	40.3
Speed in urban population zone (km/hr)	24.2
Number of crewmen	2
Distance from source to crew (meters)	10
Number of handlings	2
Stop time per km (hr/km)	0.011
Persons exposed while stopped	50
Average exposure distance while stopped (meters)	20
Storage time per shipment (hr)	0.0
Number of people per vehicle on link	2
Fraction of urban travel during rush hour traffic	0.1
Fraction of urban travel on city streets	0.0
Fraction of rural-suburban travel on freeways	1.0

The results of the RADTRAN 4.0 analysis of the transportation risks for the alternatives considered are presented in Appendix C for use in other portions of this EA.

APPENDIX B

EVALUATION OF ALTERNATIVE PORTS OF ENTRY

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EVALUATION OF ALTERNATIVE PORTS OF ENTRY

This appendix describes the approach taken in this EA to the identification and evaluation of alternative ports of entry for subsequent shipment of the imported Pu-238 fuel to either the SRS or LANL.

B.1 IDENTIFICATION OF ALTERNATIVE PORTS OF ENTRY

In identifying alternative ports of entry, DOE considered all major ports on the Atlantic, Gulf, and Pacific coasts of the United States (U.S.) as described in CIGNA (1989). The alternative ports of entry considered in this EA have been identified in Table 2-1 of the main text. A total of 36 alternative ports of entry are considered, including 15 on the Atlantic Coast, 9 on the Gulf Coast, and 12 on the Pacific Coast. As addressed in this EA these port locations include both civilian and U.S. Naval port facilities in the area of each location identified. The majority of these ports are located in large metropolitan areas. In order to consider the effect of port area population density in the evaluation, several smaller ports with low population densities have been included. Ocean distances from St. Petersburg, Russia to each port of entry, the highway distances from each port of entry to SRS and LANL, and all supporting tables related to the transportation risks associated with these alternative ports of entry are presented in Appendix C.

Although a large number of smaller ports could have been included for evaluation, up to and including all ports in the U.S. having sufficient harbor depths to accommodate an ocean cargo vessel, DOE believes this would have been excessive in the context of NEPA with respect to the need to consider a reasonable number of alternatives. Other factors important in port evaluation relate to experience, facilities, security, and safeguards. Smaller ports are likely to be less suitable from an experience viewpoint in terms of the Russian familiarity with port entry/departure and facilities, and port experience with international cargo vessels delivering shipments of radioactive materials. It is less likely that port cargo handling facilities will be suitable in terms of capability of handling the type of cargo involved and the port capacity for handling cargo in a timely manner. Also, vessel turning and maneuvering areas are more restrictive in smaller ports. These factors in the case of smaller ports translate into reduced operating flexibility for port-related activities under the proposed action and, while not quantifiable, could adversely affect accident risk.

B.2 APPROACH TAKEN IN THE EVALUATION

A number of factors were considered by DOE in evaluating the alternative ports of entry. These included both quantitative and qualitative factors reflecting exclusionary and/or evaluative screening criteria. The exclusionary factors are essentially those described in the previous section related to smaller ports that determine whether a port was included in the list of 36 ports considered in the first screening step. DOE has tentatively assumed that all the 36 ports are potentially acceptable with the port preference based on evaluative criteria. The quantitative evaluative criteria considered by DOE include:

- Ocean distance from St. Petersberg to port of entry
- Highway distances from port of entry to SRS and LANL

- Transportation health risk (including the ocean transport to the port of entry and highway transport from the port of entry to SRS or LANL)

The approach to evaluating transportation risk using the HIGHWAY 3.0 and RADTRAN 4.0 computer codes has been described in Appendix A. The transportation risks considered include those resulting from incident-free transportation (involving external exposure) and accidents (involving radioactive material release and traffic fatalities).

Qualitative evaluative criteria, although less tangible and not subject to quantification, are also important considerations in evaluating the alternatives. These criteria include:

- Experience factors related to Russian familiarity with port facilities, and port experience with international cargo vessels importing radioactive materials
- Port access in terms of direct ocean access versus the use of rivers and inland waterways
- Compatibility with existing port operations
- Safeguards and security
- Emergency response capabilities and assets

Unless available information indicated otherwise, all 36 ports have been assumed to be adequate regarding:

- Port cargo handling facilities in terms of capability of handling the type of cargo involved and the port capacity for handling cargo in a timely manner.
- Vessel turning and maneuvering areas

The latter criteria would not be expected to be an issue with the major U.S. ports considered.

B.3 EVALUATION OF ALTERNATIVES

The results of the HIGHWAY 3.0 / RADTRAN 4.0 analysis of the transportation risks associated with each alternative port of entry for the incident-free and accident scenarios considered are summarized in Appendix C for the Atlantic, Gulf, and Pacific ports, respectively. In order to understand the general features of these results it is instructive to focus first on the average results for ports along each of the three coasts (Atlantic, Gulf, and Pacific) as presented in Table B-1. Some general features of these results that can be observed include:

- The average transportation risks for each coast in terms of expectation of fatalities, including consideration of incident-free and accident conditions, range from 2.8×10^{-3} to 8.4×10^{-3} fatalities. The average risks are within about a factor of 3.0 for transport from any given coast to SRS, and within a factor of about 1.6 for transportation to LANL.

Table B-1

Average Characteristics of Alternative Ports of Entry by Coastal Group

Characteristic	Atlantic Ports	Gulf Ports	Pacific Ports
Distances, km:			
St. Petersburg to Port	8,820	11,100	17,400
Port to SRS	821	1,300	4,340
Port to LANL	3,290	2,160	2,060
St. Petersburg to SRS[a]	9,640	12,400	21,700
St. Petersburg to LANL[a]	12,100	13,300	19,500
Transportation Risks, fatalities			
St. Petersburg to SRS	2.75×10^{-3}	3.07×10^{-3}	8.35×10^{-3}
St. Petersburg to LANL	7.11×10^{-3}	4.85×10^{-3}	4.49×10^{-3}

[a] Sums are rounded.

- The average transport distances from St. Petersburg for each coast are within a factor of 2.3 for transport to SRS, and within a factor of 1.6 for transport to LANL.

When the details of the risk results are examined, it is found that the risks are dominated by those due to traffic fatalities and incident-free worker radiation exposure, rather than by accidents involving the release of Pu-238 fuel. The contribution of port accidents to the total risk of any given alternative was found to be small, approximately 10 percent. Thus, port population density does not become a discriminating factor in the quantification of risk.

The significance of the transportation risks presented in Table B-1 can be evaluated by considering the population at risk. The population affected by these risks is on the order of 10^5 persons or greater, depending on the specific port of entry. Thus, the average individual risk to a member of the public would be less than 10^{-7} for the proposed action. (Note: this is a bounding upper limit estimate since the transportation risks reported include those to both workers and the general population). According to the National Council on Radiation Protection (NCRP) in NCRP (1987) involuntary individual risks less than about 10^{-6} per year are generally acceptable. Furthermore, NCRP considers an individual risk level of less than 10^{-7} per year as a "negligible level of risk." Since the proposed action would result in an average lifetime (rather than annual) individual risk of less than 10^{-7}, DOE concludes that the transportation risks are small. Furthermore, the relative differences in average risk associated with the use of ports along the three coasts are small.

When the port-specific risks are considered, rather than coastal average risks, the same conclusions outlined above hold. Therefore, DOE concluded that although selecting a port of entry based on a minimum-risk approach is desirable when possible, it offered no clear advantages given that the total risks and relative risks of all the alternatives considered are small. This is especially true when the other evaluative criteria factors identified previously are taken into account.

Based on these considerations and the results presented in Table B-1, initial screening conclusions regarding the port-of-entry groups along the three coasts are as follows:

- For transportation to SRS, ports along the Atlantic Coast are preferable because they minimize transportation distances and risks compared to ports on the Gulf and Pacific Coasts.

- For transport to LANL, since the differences in transportation risks for ports along each of the three coasts are not significantly different (within a factor of 1.6), transportation distance then becomes a discriminating factor. Generally, for exclusive use per unit distance travelled, ocean transport is more costly, and requires more time, people, and fuel than highway transport. Due to the significantly longer total highway transport and ocean transport distances involved, the Pacific coast ports are less preferable than the Atlantic and Gulf Coast ports. For the same reason, but to a lesser degree, the Gulf Coast ports are less preferable than the Atlantic Coast ports.

- Minimizing ocean transport distances also minimizes the probability of loss of cargo at sea in case of an accident. This consideration is more of a concern from a material loss and recovery viewpoint rather than from a hazards viewpoint. As discussed in Appendix A, such a loss at sea would not be expected to pose any real hazard to the environment or result in any exposures to people. Note also that based on the information presented in Section A.2.1 of Appendix A that accident rates in the Gulf of Mexico are approximately twice those in the Atlantic. Thus, this is another reason for preferring Atlantic coast ports to Gulf coast ports for shipment to LANL.

Given that Atlantic coast ports in general were found to be preferable for shipments to both SRS and LANL to those on the Gulf and Pacific coasts, a second tier screening of Atlantic coast ports based on the evaluative criteria identified above is now considered. Transportation distances and risks for the 15 Atlantic coast ports-of-entry for transport to SRS and LANL, are presented in Appendix C (Table C-1, C-4, and C-5). The results for the Atlantic Coast ports-of-entry are summarized below:

- The transportation distances from St. Petersburg for the Atlantic coast ports-of-entry are within a factor of 1.2 of each other for transport to SRS, and within a factor of 1.1 for transport to LANL.

- The transportation risks associated with the Atlantic coast ports-of-entry and transport to SRS are within a factor of 3.0 of each other, ranging from 1.5×10^{-3} to 4.6×10^{-3} fatalities. The risks for transport to LANL are within a factor of 1.2 of each other, ranging from 6.5×10^{-3} to 8.1×10^{-3} fatalities. As discussed above, DOE considers these risks and their relative differences to be small, with a selection of a port-of-entry along the Atlantic Coast based on a risk-minimum approach offering no clear advantage when other evaluative factors are taken into account.

Based on this information and considering the other qualitative criteria identified in Section B.2, DOE has selected Hampton Roads, VA as the preferred port of entry for the proposed action. The principle reasons for this selection are as follows:

- Differences in relative risk among the alternative ports of entry along the Atlantic coast are small given the uncertainties in the analysis.

- Hampton Roads, VA has a number of commercial and U.S. Naval port facilities that could be used, thus maximizing flexibility in the required port activities under the proposed action.

- Hampton Roads has a full time port risk management staff and is experienced in handling cargo vessels importing foreign radioactive material, such as spent fuel (DOE1991b).

- The presence of the U.S. Naval port facilities would increase safety and help to assure the secure transfer of cargo from the Russian vessel to the SSTs in preparation for highway transport. In addition the emergency response capabilities and assets available at those port facilities would be advantageous in the event of an accident.

When DOE considered the commercial and U.S. Naval port facilities in the Hampton Roads area in light of the above conclusions, the Norfolk Naval Base was selected as the preferred port facility. Besides meeting basic criteria, it also would provide enhanced safeguards and security during the transfer operations of the Pu-238 fuel cargo from the Russian vessel to the SSTs. Representatives of the U.S. Navy have stated that the proposed action would be more compatible with existing operations at the Norfolk Naval Base than with operations at other U.S. Naval port facilities in the area.

APPENDIX C

HIGHWAY 3.0 AND RADTRAN 4.0 RESULTS FOR ALTERNATIVE PORTS OF ENTRY

Table C-1

Summary of Distances, Kilometers (Atlantic Ports)

Port[a]	St. Petersburg to Port	Port to		St. Petersburg to	
		SRS	LANL	SRS[b]	LANL[b]
Baltimore, MD	8,700	938	3,220	9,640	11,900
Boston, MA	7,960	1,620	3,760	9,580	11,700
Hampton Roads, VA	8,500	808	3,250	9,310	11,800
New York, NY	8,180	1,310	3,470	9,490	11,600
Philadelphia, PA	8,460	1,120	3,300	9,580	11,800
Wilmington, DE	8,410	1,070	3,330	9,480	11,700
Charleston, SC	9,000	264	3,030	9,260	12,000
Jacksonville, FL	9,260	551	3,100	9,810	12,400
Miami, FL	9,460	1,110	3,650	10,600	13,100
Morehead City, NC	8,620	614	3,250	9,230	11,900
Port Everglades, FL	9,420	1,080	3,620	10,500	13,000
Savannah, GA	9,140	354	2,930	9,490	12,100
Wilmington, NC	8,740	427	3,190	9,170	11,900
Fernandina Beach, FL	9,220	541	3,150	9,760	12,400
St. Marys, GA	9,220	510	3,160	9,730	12,400

[a] No ranking is implied in port listing.
[b] Sums are rounded.

Table C-2

Summary of Distances, Kilometers (Gulf Ports)

Port[a]	St. Petersburg to Port	Port to		St. Petersburg to	
		SRS	LANL	SRS[b]	LANL[b]
Beaumont, TX	11,300	1,400	1,919	12,700	13,200
Corpus Christi, TX	11,600	2,080	1,730	13,700	13,300
Galveston, TX	11,400	1,610	1,860	13,000	13,300
Gulfport, MS	10,900	908	2,310	11,800	13,200
Houston, TX	11,500	1,550	1,780	13,000	13,300
Mobile, AL	10,900	811	2,420	11,700	13,300
New Orleans, LA	11,000	1,020	2,230	12,000	13,200
Port Arthur, TX	11,300	1,440	1,930	12,700	13,200
Tampa, FL	10,300	911	3,270	11,200	13,600

[a] No ranking is implied in port listing.
[b] Sums are rounded.

Table C-3

Summary of Distances, Kilometers (Pacific Ports)

Port[a]	St. Petersburg to Port	Port to		St. Petersburg to	
		SRS	LANL	[b]SRS	LANL[b]
Long Beach, CA	16,600	3,960	1,530	20,600	18,100
Los Angeles, CA	16,700	3,910	1,450	20,600	18,100
Oakland, CA	17,200	4,500	2,040	21,700	19,200
Port Hueneme, CA	16,800	4,020	1,560	20,800	18,400
Richmond, CA	17,200	4,510	2,050	21,700	19,300
Sacramento, CA	17,300	4,500	2,050	21,800	19,400
San Diego, CA	16,500	3,780	1,530	20,300	18,000
San Francisco, CA	17,200	4,520	2,050	21,700	19,300
Stockton, CA	17,300	4,440	1,980	21,700	19,300
Portland, OR	18,400	4,600	2,730	23,000	21,100
Seattle, WA	18,700	4,680	2,840	23,400	21,500
Tacoma, WA	18,800	4,720	2,880	23,500	21,700

[a] No ranking is implied in port listing.

[b] Sums are rounded.

Table C-4a

Atlantic Ports Risk Summary (SRS)

Port	Port Density persons/km^2	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Baltimore, MD	3.62×10^{3}	5.93×10^{-1}	3.64×10^{-1}	4.30×10^{-2}	1.88×10^{-5}
Boston, MA	4.69×10^{3}	4.81×10^{-1}	4.33×10^{-1}	8.60×10^{-2}	4.14×10^{-5}
Hampton Roads, VA	2.00×10^{3}	6.62×10^{-1}	3.32×10^{-1}	7.00×10^{-3}	1.73×10^{-5}
New York, NY	9.30×10^{3}	5.63×10^{-1}	3.92×10^{-1}	4.50×10^{-2}	2.77×10^{-5}
Philadelphia, PA	4.66×10^{3}	5.12×10^{-1}	4.27×10^{-1}	6.20×10^{-2}	2.28×10^{-5}
Wilmington, DE	2.56×10^{3}	5.38×10^{-1}	4.25×10^{-1}	3.70×10^{-2}	2.15×10^{-5}
Charleston, SC	7.54×10^{2}	6.87×10^{-1}	2.92×10^{-1}	2.10×10^{-2}	5.20×10^{-5}
Jacksonville, FL	3.10×10^{2}	8.23×10^{-1}	1.67×10^{-1}	1.00×10^{-2}	9.70×10^{-5}
Miami, FL	4.21×10^{3}	7.42×10^{-1}	2.10×10^{-1}	4.80×10^{-2}	2.05×10^{-5}
Morehead City, NC	3.74×10^{1}	6.48×10^{-1}	3.50×10^{-1}	2.00×10^{-3}	1.42×10^{-5}
Port Everglades, FL	1.85×10^{3}	7.62×10^{-1}	2.15×10^{-1}	2.30×10^{-2}	1.99×10^{-5}
Savannah, GA	9.98×10^{2}	8.00×10^{-1}	1.94×10^{-1}	6.00×10^{-3}	6.76×10^{-6}
Wilmington, NC	6.93×10^{2}	7.55×10^{-1}	2.41×10^{-1}	4.00×10^{-3}	9.37×10^{-6}
Fernandina Beach, FL	2.50×10^{1}	8.23×10^{-1}	1.67×10^{-1}	1.00×10^{-2}	9.51×10^{-6}
St. Marys, GA	1.15×10^{1}	8.23×10^{-1}	1.67×10^{-1}	1.00×10^{-2}	8.91×10^{-6}

Table C-4b

Atlantic Ports Risk Summary (SRS)

Port	Collective Dose, person-rem				Total Risk, Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Baltimore, MD	2.49×10^{0}	1.08×10^{-1}	8.70×10^{-1}	4.38×10^{-1}	2.83×10^{-3}
Boston, MA	4.03×10^{0}	2.59×10^{-1}	8.64×10^{-1}	5.68×10^{-1}	4.60×10^{-3}
Hampton Roads, VA	2.16×10^{0}	6.75×10^{-2}	8.68×10^{-1}	2.42×10^{-1}	2.38×10^{-3}
New York, NY	3.24×10^{0}	1.61×10^{-1}	8.65×10^{-1}	1.13×10^{0}	4.22×10^{-3}
Philadelphia, PA	2.95×10^{0}	1.60×10^{-1}	8.68×10^{-1}	5.64×10^{-1}	3.36×10^{-3}
Wilmington, DE	2.78×10^{0}	1.34×10^{-1}	8.67×10^{-1}	3.10×10^{-1}	2.96×10^{-3}
Charleston, SC	1.18×10^{0}	2.21×10^{-2}	8.72×10^{-1}	9.12×10^{-2}	2.80×10^{-3}
Jacksonville, FL	1.62×10^{0}	2.60×10^{-2}	8.74×10^{-1}	3.75×10^{-2}	4.42×10^{-3}
Miami, FL	2.68×10^{0}	9.19×10^{-2}	8.76×10^{-1}	5.09×10^{-1}	3.03×10^{-3}
Morehead City, NC	1.82×10^{0}	5.18×10^{-2}	8.69×10^{-1}	4.53×10^{-3}	1.85×10^{-3}
Port Everglades, FL	2.57×10^{0}	7.26×10^{-2}	8.76×10^{-1}	2.23×10^{-1}	2.66×10^{-3}
Savannah, GA	1.30×10^{0}	1.80×10^{-2}	8.73×10^{-1}	1.21×10^{-1}	1.44×10^{-3}
Wilmington, NC	1.44×10^{0}	2.58×10^{-2}	8.70×10^{-1}	8.39×10^{-2}	1.56×10^{-3}
Fernandina Beach, FL	1.60×10^{0}	2.56×10^{-2}	8.74×10^{-1}	3.03×10^{-3}	1.57×10^{-3}
St. Marys, GA	1.55×10^{0}	2.41×10^{-2}	8.74×10^{-1}	1.39×10^{-3}	1.52×10^{-3}
				Average	2.75×10^{-3}

Table C-5a

Atlantic Ports Risk Summary (LANL)

Port	Port Density persons/km^{2}	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Baltimore, MD	3.62x10^{3}	7.39x10^{-1}	2.42x10^{-1}	2.00x10^{-2}	8.37x10^{-5}
Boston, MA	4.69x10^{3}	6.98x10^{-1}	2.75x10^{-1}	2.70x10^{-2}	9.49x10^{-5}
Hampton Roads, VA	2.00x10^{3}	7.72x10^{-1}	2.14x10^{-1}	1.60x10^{-2}	1.00x10^{-4}
New York, NY	9.30x10^{3}	7.37x10^{-1}	2.31x10^{-1}	3.20x10^{-2}	9.04x10^{-5}
Philadelphia, PA	4.66x10^{3}	7.27x10^{-1}	2.54x10^{-1}	1.90x10^{-2}	8.51x10^{-5}
Wilmington, DE	2.56x10^{3}	7.19x10^{-1}	2.61x10^{-1}	2.00x10^{-2}	8.60x10^{-5}
Charleston, SC	7.54x10^{2}	7.77x10^{-1}	2.08x10^{-1}	1.50x10^{-2}	9.42x10^{-5}
Jacksonville, FL	3.10x10^{2}	7.88x10^{-1}	1.92x10^{-1}	2.00x10^{-2}	8.87x10^{-5}
Miami, FL	4.21x10^{3}	7.69x10^{-1}	2.02x10^{-1}	2.90x10^{-2}	9.96x10^{-5}
Morehead City, NC	3.47x10^{1}	7.38x10^{-1}	2.49x10^{-1}	1.30x10^{-2}	1.01x10^{-4}
Port Everglades, FL	1.85x10^{3}	7.75x10^{-1}	2.03x10^{-1}	2.20x10^{-2}	9.88x10^{-5}
Savannah, GA	9.98x10^{2}	7.97x10^{-1}	1.84x10^{-1}	1.90x10^{-2}	9.12x10^{-5}
Wilmington, NC	6.93x10^{2}	7.81x10^{-1}	2.06x10^{-1}	1.30x10^{-2}	9.92x10^{-5}
Fernandina Beach, FL	2.50x10^{1}	7.88x10^{-1}	1.92x10^{-1}	2.00x10^{-2}	8.88x10^{-5}
St. Marys, GA	1.15x10^{1}	7.88x10^{-1}	1.92x10^{-1}	2.00x10^{-2}	8.88x10^{-5}

Table C-5b

Atlantic Ports Risk Summary (LANL)

Port	Collective Dose, person-rem				Total Risk, Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Baltimore, MD	$6.34x10^{0}$	$2.30x10^{-1}$	$8.70x10^{-1}$	$4.38x10^{-1}$	$6.95x10^{-3}$
Boston, MA	$7.44x10^{0}$	$3.15x10^{-1}$	$8.64x10^{-1}$	$5.68x10^{-1}$	$8.07x10^{-3}$
Hampton Roads, VA	$6.29x10^{0}$	$2.02x10^{-1}$	$8.68x10^{-1}$	$2.42x10^{-1}$	$7.22x10^{-3}$
New York, NY	$6.81x10^{0}$	$2.67x10^{-1}$	$8.66x10^{-1}$	$1.13x10^{0}$	$8.13x10^{-3}$
Philadelphia, PA	$6.49x10^{0}$	$2.42x10^{-1}$	$8.68x10^{-1}$	$5.64x10^{-1}$	$7.21x10^{-3}$
Wilmington, DE	$6.57x10^{0}$	$2.52x10^{-1}$	$8.67x10^{-1}$	$3.10x10^{-1}$	$7.03x10^{-3}$
Charleston, SC	$5.87x10^{0}$	$1.82x10^{-1}$	$8.72x10^{-1}$	$9.12x10^{-2}$	$6.66x10^{-3}$
Jacksonville, FL	$5.97x10^{0}$	$1.85x10^{-1}$	$8.75x10^{-1}$	$3.75x10^{-2}$	$6.49x10^{-3}$
Miami, FL	$7.03x10^{0}$	$2.49x10^{-1}$	$8.76x10^{-1}$	$5.09x10^{-1}$	$7.90x10^{-3}$
Morehead City, NC	$6.35x10^{0}$	$2.22x10^{-1}$	$8.69x10^{-1}$	$4.20x10^{-3}$	$7.07x10^{-3}$
Port Everglades, FL	$6.93x10^{0}$	$2.31x10^{-1}$	$8.76x10^{-1}$	$2.23x10^{-1}$	$7.52x10^{-3}$
Savannah, GA	$5.67x10^{0}$	$1.68x10^{-1}$	$8.74x10^{-1}$	$1.21x10^{-1}$	$6.48x10^{-3}$
Wilmington, NC	$6.13x10^{0}$	$1.86x10^{-1}$	$8.70x10^{-1}$	$8.39x10^{-2}$	$6.94x10^{-3}$
Fernandina Beach, FL	$6.07x10^{0}$	$1.89x10^{-1}$	$8.74x10^{-1}$	$3.03x10^{-3}$	$6.51x10^{-3}$
St. Marys, GA	$6.09x10^{0}$	$1.89x10^{-1}$	$8.74x10^{-1}$	$1.40x10^{-3}$	$6.52x10^{-3}$
				Average	$7.11x10^{-3}$

Table C-6a

Gulf Ports Risk Summary (SRS)

Port	Port Density persons/km^2	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Beaumont, TX	$6.26\text{x}10^{2}$	$6.69\text{x}10^{-1}$	$3.16\text{x}10^{-1}$	$1.50\text{x}10^{-2}$	$3.08\text{x}10^{-5}$
Corpus Christi, TX	$8.68\text{x}10^{2}$	$7.00\text{x}10^{-1}$	$2.77\text{x}10^{-1}$	$2.30\text{x}10^{-2}$	$4.56\text{x}10^{-5}$
Galveston, TX	$4.82\text{x}10^{2}$	$6.48\text{x}10^{-1}$	$3.32\text{x}10^{-1}$	$2.00\text{x}10^{-2}$	$3.53\text{x}10^{-5}$
Gulfport, MS	$7.48\text{x}10^{2}$	$6.85\text{x}10^{-1}$	$3.04\text{x}10^{-1}$	$1.10\text{x}10^{-2}$	$1.98\text{x}10^{-5}$
Houston, TX	$1.17\text{x}10^{3}$	$6.64\text{x}10^{-1}$	$3.11\text{x}10^{-1}$	$2.50\text{x}10^{-2}$	$3.40\text{x}10^{-5}$
Mobile, AL	$5.74\text{x}10^{2}$	$7.12\text{x}10^{-1}$	$2.70\text{x}10^{-1}$	$1.80\text{x}10^{-2}$	$1.61\text{x}10^{-5}$
New Orleans, LA	$1.07\text{x}10^{3}$	$6.84\text{x}10^{-1}$	$2.91\text{x}10^{-1}$	$2.50\text{x}10^{-2}$	$2.22\text{x}10^{-5}$
Port Arthur, TX	$2.88\text{x}10^{2}$	$6.56\text{x}10^{-1}$	$3.29\text{x}10^{-1}$	$1.60\text{x}10^{-2}$	$3.15\text{x}10^{-5}$
Tampa, FL	$1.03\text{x}10^{3}$	$7.34\text{x}10^{-1}$	$2.48\text{x}10^{-1}$	$1.80\text{x}10^{-2}$	$1.66\text{x}10^{-5}$

Table C-6b

Gulf Ports Risk Summary (SRS)

Port	Collective Dose, person-rem				Total Risk, Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Beaumont, TX	3.24×10^{0}	1.20×10^{-1}	8.92×10^{-1}	7.57×10^{-2}	3.24×10^{-3}
Corpus Christi, TX	4.42×10^{0}	1.70×10^{-1}	8.95×10^{-1}	1.05×10^{-1}	4.39×10^{-3}
Galveston, TX	3.65×10^{0}	1.49×10^{-1}	8.93×10^{-1}	5.83×10^{-2}	3.61×10^{-3}
Gulfport, MS	2.33×10^{0}	7.24×10^{-2}	8.88×10^{-1}	9.05×10^{-2}	2.40×10^{-3}
Houston, TX	3.53×10^{0}	1.41×10^{-1}	8.93×10^{-1}	1.41×10^{-1}	3.58×10^{-3}
Mobile, AL	2.14×10^{0}	6.21×10^{-2}	8.89×10^{-1}	6.95×10^{-2}	2.16×10^{-3}
New Orleans, LA	2.54×10^{0}	8.78×10^{-2}	8.89×10^{-1}	1.30×10^{-1}	2.64×10^{-3}
Port Arthur, TX	3.32×10^{0}	1.28×10^{-1}	8.92×10^{-1}	3.48×10^{-2}	3.27×10^{-3}
Tampa, FL	2.30×10^{0}	6.51×10^{-2}	8.83×10^{-1}	1.25×10^{-1}	2.31×10^{-3}
				Average	3.07×10^{-3}

Table C-7a

Gulf Ports Risk Summary (LANL)

Port	Port Density persons/km^{2}	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Beaumont, TX	6.26×10^{2}	7.84×10^{-1}	1.81×10^{-1}	3.50×10^{-2}	5.56×10^{-5}
Corpus Christi, TX	8.68×10^{2}	8.67×10^{-1}	1.11×10^{-1}	2.20×10^{-2}	5.02×10^{-5}
Galveston, TX	4.82×10^{2}	7.63×10^{-1}	2.00×10^{-1}	3.70×10^{-2}	5.42×10^{-5}
Gulfport, MS	7.48×10^{2}	8.03×10^{-1}	1.70×10^{-1}	2.70×10^{-2}	6.50×10^{-5}
Houston, TX	1.17×10^{3}	7.92×10^{-1}	1.73×10^{-1}	3.50×10^{-2}	5.17×10^{-5}
Mobile, AL	5.74×10^{2}	7.87×10^{-1}	1.85×10^{-1}	2.80×10^{-2}	6.83×10^{-5}
New Orleans, LA	1.07×10^{3}	8.00×10^{-1}	1.62×10^{-1}	3.80×10^{-2}	6.27×10^{-5}
Port Arthur, TX	2.88×10^{2}	7.76×10^{-1}	1.88×10^{-1}	3.60×10^{-2}	5.62×10^{-5}
Tampa, FL	1.03×10^{3}	7.90×10^{-1}	1.89×10^{-1}	2.10×10^{-2}	9.20×10^{-5}

Table C-7b

Gulf Ports Risk Summary (LANL)

Port	Collective Dose, person-rem				Total Risk, Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Beaumont, TX	4.00×10^{0}	1.29×10^{-1}	8.92×10^{-1}	7.57×10^{-2}	4.43×10^{-3}
Corpus Christi, TX	3.53×10^{0}	7.30×10^{-2}	8.95×10^{-1}	1.05×10^{-1}	3.99×10^{-3}
Galveston, TX	3.95×10^{0}	1.36×10^{-1}	8.93×10^{-1}	5.83×10^{-2}	4.35×10^{-3}
Gulfport, MS	4.63×10^{0}	1.38×10^{-1}	8.88×10^{-1}	9.05×10^{-2}	5.07×10^{-3}
Houston, TX	3.75×10^{0}	1.16×10^{-1}	8.93×10^{-1}	1.41×10^{-1}	4.24×10^{-3}
Mobile, AL	4.85×10^{0}	1.54×10^{-1}	8.89×10^{-1}	6.95×10^{-2}	5.28×10^{-3}
New Orleans, LA	4.53×10^{0}	1.45×10^{-1}	8.89×10^{-1}	1.30×10^{-1}	4.99×10^{-3}
Port Arthur, TX	4.05×10^{0}	1.35×10^{-1}	8.92×10^{-1}	3.48×10^{-2}	4.44×10^{-3}
Tampa, FL	6.27×10^{0}	1.95×10^{-1}	8.83×10^{-1}	1.25×10^{-1}	6.84×10^{-3}
				Average	4.85×10^{-3}

Table C-8a

Pacific Ports Risk Summary (SRS)

Port	Port Density persons/km^2	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Long Beach, CA	3.07×10^{3}	7.65×10^{-1}	2.10×10^{-1}	2.50×10^{-2}	9.77×10^{-5}
Los Angeles, CA	2.70×10^{3}	7.67×10^{-1}	2.08×10^{-1}	2.50×10^{-2}	9.75×10^{-5}
Oakland, CA	2.56×10^{3}	7.78×10^{-1}	1.95×10^{-1}	2.70×10^{-2}	1.07×10^{-4}
Port Hueneme, CA	1.99×10^{3}	7.60×10^{-1}	2.15×10^{-1}	2.50×10^{-2}	1.00×10^{-4}
Richmond, CA	1.03×10^{3}	7.76×10^{-1}	1.96×10^{-1}	2.80×10^{-2}	1.07×10^{-4}
Sacramento, CA	1.28×10^{3}	8.17×10^{-1}	1.67×10^{-1}	1.60×10^{-2}	1.06×10^{-4}
San Diego, CA	1.19×10^{3}	7.98×10^{-1}	1.89×10^{-1}	1.30×10^{-2}	9.49×10^{-5}
San Francisco, CA	6.23×10^{3}	7.76×10^{-1}	1.97×10^{-1}	2.70×10^{-2}	1.07×10^{-4}
Stockton, CA	1.65×10^{3}	7.84×10^{-1}	1.94×10^{-1}	2.20×10^{-2}	1.05×10^{-4}
Portland, OR	1.32×10^{3}	8.10×10^{-1}	1.80×10^{-1}	1.00×10^{-2}	1.01×10^{-4}
Seattle, WA	2.25×10^{3}	8.23×10^{-1}	1.70×10^{-1}	7.00×10^{-3}	1.08×10^{-4}
Tacoma, WA	1.28×10^{3}	8.16×10^{-1}	1.76×10^{-1}	8.00×10^{-3}	1.09×10^{-4}

Table C-8b

Pacific Ports Risk Summary (SRS)

Port	Collective Dose, person rem				Risk Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Long Beach, CA	$7.56\text{x}10^{0}$	$2.67\text{x}10^{-1}$	$9.36\text{x}10^{-1}$	$3.72\text{x}10^{-1}$	$8.01\text{x}10^{-3}$
Los Angeles, CA	$7.46\text{x}10^{0}$	$2.62\text{x}10^{-1}$	$9.37\text{x}10^{-1}$	$3.27\text{x}10^{-1}$	$7.91\text{x}10^{-3}$
Oakland, CA	$8.44\text{x}10^{0}$	$2.94\text{x}10^{-1}$	$9.41\text{x}10^{-1}$	$3.09\text{x}10^{-1}$	$8.72\text{x}10^{-3}$
Port Hueneme, CA	$7.67\text{x}10^{0}$	$2.75\text{x}10^{-1}$	$9.37\text{x}10^{-1}$	$2.41\text{x}10^{-1}$	$8.02\text{x}10^{-3}$
Richmond, CA	$8.47\text{x}10^{0}$	$2.98\text{x}10^{-1}$	$9.41\text{x}10^{-1}$	$1.24\text{x}10^{-1}$	$8.55\text{x}10^{-3}$
Sacramento, CA	$8.22\text{x}10^{0}$	$2.31\text{x}10^{-1}$	$9.42\text{x}10^{-1}$	$1.55\text{x}10^{-1}$	$8.36\text{x}10^{-3}$
San Diego, CA	$7.07\text{x}10^{0}$	$2.05\text{x}10^{-1}$	$9.35\text{x}10^{-1}$	$1.44\text{x}10^{-1}$	$7.39\text{x}10^{-3}$
San Francisco, CA	$8.48\text{x}10^{0}$	$2.97\text{x}10^{-1}$	$9.41\text{x}10^{-1}$	$7.54\text{x}10^{-1}$	$9.19\text{x}10^{-3}$
Stockton, CA	$8.29\text{x}10^{0}$	$2.74\text{x}10^{-1}$	$9.42\text{x}10^{-1}$	$2.00\text{x}10^{-1}$	$8.45\text{x}10^{-3}$
Portland, OR	$8.38\text{x}10^{0}$	$2.31\text{x}10^{-1}$	$9.51\text{x}10^{-1}$	$1.59\text{x}10^{-1}$	$8.29\text{x}10^{-3}$
Seattle, WA	$8.46\text{x}10^{0}$	$2.15\text{x}10^{-1}$	$9.54\text{x}10^{-1}$	$2.72\text{x}10^{-1}$	$8.65\text{x}10^{-3}$
Tacoma, WA	$8.56\text{x}10^{0}$	$2.27\text{x}10^{-1}$	$9.54\text{x}10^{-1}$	$1.55\text{x}10^{-1}$	$8.63\text{x}10^{-3}$
				Average	$8.35\text{x}10^{-3}$

Table C-9a
Pacific Ports Risk Summary (LANL)

Port	Port Density persons/km^2	Fraction of Route in Zone			Traffic Fatalities/SST One Way
		Rural	Suburban	Urban	
Long Beach, CA	3.07×10^{3}	8.11×10^{-1}	1.09×10^{-1}	8.00×10^{-2}	4.05×10^{-5}
Los Angeles, CA	2.70×10^{3}	8.58×10^{-1}	9.90×10^{-2}	4.40×10^{-2}	3.91×10^{-5}
Oakland, CA	2.56×10^{3}	8.55×10^{-1}	1.03×10^{-1}	4.20×10^{-2}	4.81×10^{-5}
Port Hueneme, CA	1.99×10^{3}	8.34×10^{-1}	1.26×10^{-1}	4.00×10^{-2}	4.21×10^{-5}
Richmond, CA	1.03×10^{3}	8.52×10^{-1}	1.04×10^{-1}	4.40×10^{-2}	4.83×10^{-5}
Sacramento, CA	1.28×10^{3}	8.60×10^{-1}	9.90×10^{-2}	4.10×10^{-2}	4.87×10^{-5}
San Diego, CA	1.19×10^{3}	8.51×10^{-1}	1.39×10^{-1}	1.00×10^{-2}	4.08×10^{-5}
San Francisco, CA	6.23×10^{3}	8.50×10^{-1}	1.07×10^{-1}	4.30×10^{-2}	4.85×10^{-5}
Stockton, CA	1.65×10^{3}	8.70×10^{-1}	9.80×10^{-2}	3.20×10^{-2}	4.70×10^{-5}
Portland, OR	1.32×10^{3}	8.67×10^{-1}	1.15×10^{-1}	1.80×10^{-2}	6.26×10^{-5}
Seattle, WA	2.25×10^{3}	8.55×10^{-1}	1.30×10^{-1}	1.50×10^{-2}	6.39×10^{-5}
Tacoma, WA	1.28×10^{3}	8.43×10^{-1}	1.40×10^{-1}	1.70×10^{-2}	6.48×10^{-5}

Table C-9b

Pacific Ports Risk Summary (LANL)

Port	Collective Dose, person-rem				Total Risk, Fatalities
	Highway Transport		Ocean Transport		
	Normal	Accident	Normal	Accident	
Long Beach, CA	$3.40x10^{0}$	$1.24x10^{-1}$	$9.36x10^{-1}$	$3.72x10^{-1}$	$3.96x10^{-3}$
Los Angeles, CA	$3.12x10^{0}$	$7.87x10^{-2}$	$9.37x10^{-1}$	$3.27x10^{-1}$	$3.69x10^{-3}$
Oakland, CA	$4.11x10^{0}$	$1.10x10^{-1}$	$9.41x10^{-1}$	$3.09x10^{-1}$	$4.48x10^{-3}$
Port Hueneme, CA	$3.33x10^{0}$	$9.02x10^{-2}$	$9.37x10^{-1}$	$2.41x10^{-1}$	$3.81x10^{-3}$
Richmond, CA	$4.13x10^{0}$	$1.14x10^{-1}$	$9.41x10^{-1}$	$1.24x10^{-1}$	$4.32x10^{-3}$
Sacramento, CA	$4.12x10^{0}$	$1.08x10^{-1}$	$9.42x10^{-1}$	$1.55x10^{-1}$	$4.35x10^{-3}$
San Diego, CA	$3.20x10^{0}$	$6.21x10^{-2}$	$9.35x10^{-1}$	$1.44x10^{-1}$	$3.58x10^{-3}$
San Francisco, CA	$4.14x10^{0}$	$1.14x10^{-1}$	$9.41x10^{-1}$	$7.54x10^{-1}$	$4.96x10^{-3}$
Stockton, CA	$3.96x10^{0}$	$9.12x10^{-2}$	$9.42x10^{-1}$	$2.00x10^{-1}$	$4.25x10^{-3}$
Portland, OR	$5.15x10^{0}$	$1.11x10^{-1}$	$9.51x10^{-1}$	$1.59x10^{-1}$	$5.32x10^{-3}$
Seattle, WA	$5.36x10^{0}$	$1.19x10^{-1}$	$9.54x10^{-1}$	$2.72x10^{-1}$	$5.59x10^{-3}$
Tacoma, WA	$5.46x10^{0}$	$1.32x10^{-1}$	$9.54x10^{-1}$	$1.55x10^{-1}$	$5.57x10^{-3}$
				Average	$4.49x10^{-3}$