APPENDIX D
EVALUATION OF HUMAN HEALTH EFFECTS OF OVERLAND TRANSPORTATION

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D.1 Introduction

Transportation of any commodity involves a risk to both transportation crewmembers and members of the public. This risk results directly from transportation-related accidents and indirectly from the increased levels of pollution from vehicle emissions, regardless of the cargo. The transportation of certain materials, such as hazardous or radioactive substances, can pose an additional risk because of the nature of the material itself. To permit a complete appraisal of the environmental impacts of the Proposed Action and alternatives, the human health risks associated with the transportation of radioactive materials are analyzed in this appendix.

This appendix provides an overview of the approach used to assess the human health risks that could result from transportation. The topics in this appendix include the scope of the assessment, packaging and determination of potential transportation routes, analytical methods used for the risk assessment (e.g., computer models), and important assessment assumptions. It also presents the results of the assessment. In addition, to aid in the understanding and interpretation of the results, specific areas of uncertainty are described with an emphasis on how the uncertainties could affect comparisons of the alternatives.

The risk assessment results are presented in this appendix in terms of "per shipment" risk factors, as well as the total risks under a given alternative. Per-shipment risk factors provide an estimate of the risk from a single shipment. The total risks under a given alternative are estimated by multiplying the expected number of shipments by the appropriate per-shipment risk factors.

D.2 Scope of Assessment

The scope of the transportation human health risk assessment, including the alternatives and options, transportation activities, potential radiological and nonradiological impacts, and transportation modes considered, is described in this section. There are specific shipping arrangements for various radioactive substances that cover the alternatives evaluated. This evaluation focuses on using on- and offsite public roads or private roads. Additional details of the assessment are provided in the remaining sections of this appendix.

D.2.1 Transportation-Related Activities

The transportation risk assessment is limited to estimating the human health risks related to transportation under each alternative. The risks to workers or the public during loading, unloading, and handling at U.S. Department of Energy (DOE) facilities, prior to or after shipment, are not included in the transportation assessment. The risks from these activities are considered as part of the facility operation impacts.

D.2.2 Radiological Impacts

For each alternative, radiological risks (i.e., those risks that result from the radioactive nature of the materials) are assessed for both incident-free (i.e., normal) and accident transportation conditions. The radiological risk associated with incident-free transportation conditions would result from the potential exposure of people to external radiation in the vicinity of a shipment. The radiological risk from transportation accidents would come from the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people.

All radiological impacts are calculated in terms of committed dose and associated health effects in the exposed populations. The radiation dose calculated is the total effective dose equivalent (see Title 10 of the *Code of Federal Regulations*, Part 20 [10 CFR 20]), which is the sum of the effective dose equivalent from external radiation exposure and the 50-year committed effective dose equivalent from internal radiation exposure. Radiation doses are presented in units of roentgen equivalent man (rem) for individuals and person-rem for collective populations. The impacts are further expressed as health risks in terms of latent cancer fatalities (LCFs) in exposed populations using the dose-to-risk conversion factors recommended by DOE's Office of National Environmental Policy Act (NEPA) Policy and Compliance, based on Interagency Steering Committee on Radiation Safety guidance (DOE 2003).

D.2.3 Nonradiological Impacts

In addition to the radiological risks posed by transportation activities, vehicle-related risks are also assessed for nonradiological causes (i.e., causes related to the transport vehicles and not the radioactive cargo) for the same transportation routes. The nonradiological transportation risks, which would be incurred for similar shipments of any commodity, are assessed for both incident-free and accident conditions. The nonradiological risks during incident-free transportation conditions would be caused by potential exposure to increased vehicle exhaust emissions. The nonradiological accident risk refers to the potential occurrence of transportation accidents that directly result in fatalities unrelated to the shipment of cargo. Nonradiological risks are presented in terms of estimated fatalities.

D.2.4 Transportation Modes

All shipments are assumed to take place by dedicated truck transportation modes. Those requiring secure shipment would use DOE's Safe, Secure Trailer/Safeguards Transports (SST/SGTs).

D.2.5 Receptors

Transportation-related risks are calculated and presented separately for workers and members of the general public. The workers considered are truck and rail crewmembers involved in transportation and inspection of the packages. The general public includes all persons who could be exposed to a shipment while it is moving or stopped during transit. For the incident-free operation, the affected population includes individuals living within 800 meters (0.5 miles) of each side of the road or rail. Potential risks are estimated for the affected populations and for the hypothetical maximally exposed individual (MEI). For incident-free operation, the MEI would be a resident living near the highway or railroad and exposed to all shipments transported on the road or rail. For accident conditions, the affected population includes individuals residing within 80 kilometers (50 miles) of the accident, and the MEI would be an individual located 100 meters (330 feet) directly downwind from the accident. The risk to the affected population is a measure of the radiological risk posed to society as a whole by the alternative being considered. As such, the impact on the affected population is used as the primary means of comparing various alternatives.

D.3 Packaging and Transportation Regulations

D.3.1 Packaging Regulations

The primary regulatory approach to promote safety from radiological exposure is the specification of standards for the packaging of radioactive materials. Packaging represents the primary barrier between the radioactive material being transported and radiation exposure to the public, workers, and the environment. Transportation packaging for radioactive materials must be designed, constructed, and maintained to contain and shield its contents during normal transport conditions. For highly radioactive material, such as high-level radioactive waste or spent nuclear fuel, packagings must contain and shield their contents in the event of severe accident conditions. The type of packaging used is determined by the total radioactive hazard presented by the material within the packaging. Four basic types of packaging are used: Excepted, Industrial, Type A, and Type B. "Strong and Tight" packaging is also used to transport certain low-specific-activity materials. Strong and Tight packaging is equivalent to Type A packaging.

Excepted packagings are limited to transporting materials with extremely low levels of radioactivity. Industrial packagings are used to transport materials that, because of their low concentration of radioactive materials, present a limited hazard to the public and the environment. Type A packagings are designed to protect and retain their contents under normal transport conditions and must maintain sufficient shielding to limit radiation exposure to handling personnel. Type A packaging, typically a 0.21-cubic-meter (55-gallon) drum or standard waste box, is commonly used to transport radioactive materials with higher concentrations or amounts of radioactivity than Excepted or Industrial packagings. Strong and Tight packagings are used in the United States for shipment of certain materials with low levels of radioactivity, such as natural uranium and rubble from the decommissioning of nuclear facilities. Type B packagings are used to transport material with the highest radioactivity levels, and are designed to protect and retain their contents under severe transportation accident conditions. They are described in more detail in the following sections. Packaging requirements are an important consideration for transportation risk assessment.

D.3.2 Transportation Regulations

The regulatory standards for packaging and transporting radioactive materials are designed to achieve four primary objectives:

- Protect persons and property from radiation emitted from packages during transportation by specific limitations on the allowable radiation levels,
- Contain radioactive material (achieved by packaging design requirements based on performance-oriented packaging integrity tests and environmental criteria),
- Prevent nuclear criticality (an unplanned nuclear chain reaction that can occur as a result of concentrating too much fissile material in one place), and
- Provide physical protection against theft and sabotage during transit.

The U.S. Department of Transportation (DOT) regulates the transportation of hazardous materials in interstate commerce by land, air, and water. DOT specifically regulates the carriers of radioactive materials and the conditions of transport, such as routing, handling and storage, and vehicle and driver requirements. DOT also regulates the labeling, classification, and marking of radioactive material packagings.

The U.S. Nuclear Regulatory Commission (NRC) regulates the packaging and transporting of radioactive material for its licensees, including commercial shippers of radioactive materials. In addition, under an agreement with DOT, NRC sets the standards for packages containing fissile materials and Type B packagings.

DOE, through its management directives, Orders, and contractual agreements, ensures the protection of public health and safety by imposing on its transportation activities standards equivalent to those of DOT and NRC. According to "U.S. Government Material" (49 CFR 173.7(d)), packagings built by or under the direction of DOE may be used for transporting Class 7 (radioactive) materials when they are evaluated, approved, and certified by DOE against packaging standards equivalent to those specified in "Packaging and Transportation of Radioactive Material" (10 CFR 71).

DOT also has requirements that help to reduce transportation impacts. Some requirements affect drivers, packaging, labeling, marking, and placarding. Others, specifying the maximum dose rate from radioactive material shipments, help to reduce incident-free transportation doses.

The Federal Emergency Management Agency (FEMA), an agency of the Department of Homeland Security, is responsible for establishing policies for, and coordinating civil emergency management, planning, and interaction with, Federal agencies that have emergency response functions in the event of a transportation incident. FEMA coordinates Federal and state participation in developing emergency response plans and is responsible for development of the interim Federal Radiological Emergency Response Plan. This plan is designed to coordinate Federal support to state and local governments, upon request, during the event of a transportation incident.

The Interstate Commerce Commission is responsible for regulation of the economic aspects of overland shipments of radioactive materials. The commission issues operating authorities to carriers and also monitors and approves freight rates.

D.4 Transportation Impact Analysis Methodology

The transportation risk assessment is based on the alternatives described in Chapter 2 of the EIS. **Figure D–1** summarizes the transportation risk assessment methodology. After the *Consolidation EIS* alternatives were identified and the requirements of the shipping campaign were understood, data were collected on the material characteristics and accident parameters.

Transportation impacts calculated in this *Consolidation EIS* are presented in two parts: impacts of incident-free or routine transportation and impacts of transportation accidents. Impacts of incident-free transportation and transportation accidents were further divided into nonradiological and radiological impacts. Nonradiological impacts of incident-free transportation could result from vehicular emissions and from transportation accidents in terms of traffic fatalities. Radiological impacts of incident-free transportation include impacts on members of the public and crew from radiation emanating from materials within the packages. Only under worst-case accident conditions, which are of low probability of occurrence, could a transportation package of the type used to transport the radioactive material be damaged to the point that radioactivity could be released to the environment.

The impacts of transportation accidents are expressed in terms of probabilistic risk, which is the probability of an accident multiplied by the consequences of that accident and summed over all reasonably conceivable accident conditions. Hypothetical transportation accident conditions ranging from low-speed "fender bender" collisions to high-speed collisions, with or without fires, were analyzed. The frequencies of accidents and consequences were evaluated using a method developed by NRC and originally published in the *Final Environmental Statement on the Transportation of Radioactive Materials by Air and Other Modes*, (*Radioactive Material Transportation Study*) (NRC 1977); *Shipping Container Response to Severe Highway and Railway Accident Conditions (Modal Study)* (NRC 1987); and *Reexamination of Spent Fuel Shipping Risk Estimates (Reexamination Study)* (NRC 2000). Radiological accident risk is expressed in terms of additional LCFs, and nonradiological accident risk is expressed in terms of additional immediate (traffic) fatalities. Incident-free risk is also expressed in terms of additional LCFs.

Transportation-related risks are calculated and presented separately for workers and members of the general public. The workers considered are truck/rail crewmembers involved in the actual transportation. The general public includes all persons who could be exposed to a shipment while it is moving or stopped during transit.

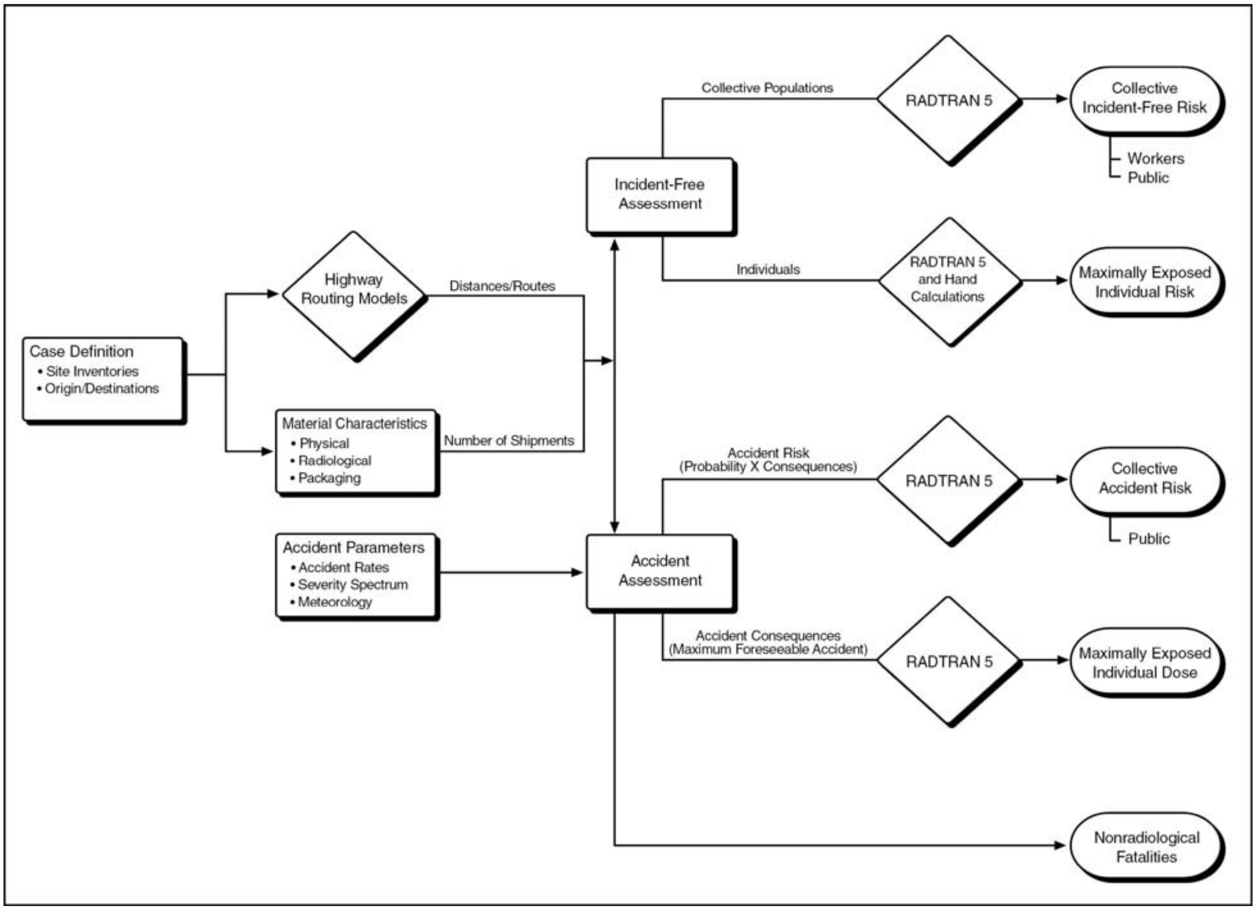

Figure D–1 Overland Transportation Risk Assessment

The first step in the ground transportation analysis is to determine the distances and populations along the routes. The Transportation Routing Analysis Geographic Information System (TRAGIS) computer program (Johnson and Michelhaugh 2003) was used to choose representative routes and the associated distances and populations. This information, along with the properties of the material being shipped and route-specific accident frequencies, was entered into the RADTRAN 5 computer code (SNL 2003), which calculates incident and accident risks on a per-shipment basis. The risks under each alternative are determined by summing the products of per-shipment risks for each radioactive substance by its number of shipments.

The RADTRAN 5 computer code (SNL 2003) is used for incident-free and accident risk assessments to estimate the impacts on populations. RADTRAN 5 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. RADTRAN 5 was used to calculate the doses to the MEIs during incident-free operations.

The RADTRAN 5 population risk calculations include both the consequences and probabilities of potential exposure events. The RADTRAN 5 code consequence analyses include cloud shine, ground shine, inhalation, and resuspension exposures. The collective population risk is a measure of the total radiological risk posed to society as a whole by the alternative being considered. As such, the collective population risk is used as the primary means of comparing the various alternatives.

The RISKIND computer code (Yuan et al. 1995) is used to estimate the doses to MEIs and populations for the worst-case maximum reasonably foreseeable transportation accident. The RISKIND computer code was developed for DOE's Office of Civilian Radioactive Waste Management to analyze the exposure of individuals during incident-free transportation. In addition, the RISKIND code was designed to allow a detailed assessment of the consequences to individuals and population subgroups of severe transportation accidents under various environmental settings.

The RISKIND calculations were conducted to supplement the collective risk results calculated with RADTRAN 5. Whereas the collective risk results provide a measure of the overall risks under each alternative, the RISKIND calculations are meant to address areas of specific concern to individuals and population subgroups. Essentially, the RISKIND analyses are meant to address "What if" questions, such as "What if I live next to a site access road?" or "What if an accident happens near my town?"

D.4.1 Transportation Routes

To assess incident-free and transportation accident impacts, route characteristics were determined for offsite shipments between Idaho National Laboratory (INL), Oak Ridge National Laboratory (ORNL), and Los Alamos National Laboratory (LANL). For offsite transports, potential highway routes were determined using the routing computer program TRAGIS (Johnson and Michelhaugh 2003).

The TRAGIS computer program is a geographic-information-system-based transportation analysis computer program used to identify/select highway, rail, and waterway routes for transporting radioactive materials within the United States. Both the road and rail network are 1:100,000-scale databases, which were developed from the U.S. Geological Survey digital line graphs and the U.S. Bureau of the Census Topological Integrated Geographic Encoding and Referencing System. The population densities along each route are derived from 2000 Census data. The features in TRAGIS allow users to determine routes for shipment of radioactive materials that conform to DOT regulations as specified in "Transportation of Hazardous Materials; Driving and Parking Rules" (49 CFR 397).

Offsite Route Characteristics

Route characteristics important to the radiological risk assessment include the total shipment distance and the population distribution along the route. The specific route selected determines both the total potentially exposed population and the expected frequency of transportation-related accidents. Analyzed route characteristics are summarized in **Table D–1**. The population densities along each route are derived from 2000 Census data (Johnson and Michelhaugh 2003). Rural, suburban, and urban areas are characterized according to the following breakdown:

- Rural population densities range from 0 to 54 persons per square kilometer (0 to 139 persons per square mile),
- Suburban population densities range from 55 to 1,284 persons per square kilometer (140 to 3,326 persons per square mile), and
- Urban population densities include all population densities greater than 1,284 persons per square kilometer (3,326 persons per square mile).

The affected population, for route characterization and incident-free dose calculation, includes all persons living within 800 meters (0.5 miles) of each side of the road. Truck routes analyzed for shipments of radioactive materials are shown in **Figure D–2**.

Table D–1 Offsite Transport Truck Route Characteristics

From	To	Nominal Distance (kilometers)	Distance Traveled in Zones (kilometers)			Population Density in Zone (number per square kilometer)			Number of Affected Persons
			Rural	Suburban	Urban	Rural	Suburban	Urban	
Truck Routes									
INL	ORNL	3,369	2,684	631	54	11.5	300.5	2,200.6	543,647
ORNL	LANL	2,370	1,827	478	65	11.0	304.2	2,260.9	500,379
LANL	INL	1,878	1,551	282	45	8.0	354.1	2,325.7	347,910
Pantex	INL [a]	1,762	1,535	184	43	5.3	408.5	2,354.8	294,603

INL = Idaho National Laboratory, ORNL = Oak Ridge National Laboratory, LANL = Los Alamos National Laboratory.

[a] This route is used for transport of plutonium-238 heat sources within milliwatt generators removed from dismantled nuclear weapons.

Note: To convert from kilometers to miles, multiply by 0.6214; to convert from number per square kilometer to number per square mile, multiply by 2.59.

Onsite Route Characteristics

The onsite transport of various radioactive substances is either within a facility, or within a national laboratory site using private roads. Onsite transport occurs at ORNL between the Radiochemical Engineering Development Center (REDC) and the High Flux Isotope Reactor (HFIR), and at INL between the Materials and Fuels Complex (MFC) (formerly known as Argonne National Laboratory-West) and the Advanced Test Reactor (ATR). The REDC and HFIR facilities are about 100 meters (109 yards) apart, and transport occurs on closed roads entirely within the 7900 Area of the ORNL. DOE is proposing to construct a private service road with access restricted to INL contractor material transfers between MFC and ATR. This road would be located entirely within the INL site boundary and closed to the public. Therefore, public population density around these onsite transport roads would be zero.

D.4.2 Radioactive Material Shipments

DOE anticipates that any transportation of neptunium or plutonium dioxide would be required to use the Transportation Safeguards System and SST/SGT shipments. The SST/SGT is a fundamental component of the Transportation Safeguards System, which is operated by the Transportation Safeguards Division of the DOE Albuquerque Operations Office.

Neptunium is handled under safeguards applicable to special nuclear material in accordance with DOE Office of Safeguards and Security guidance. Pure neptunium-237 could potentially be used as nuclear weapons material; therefore, it is shipped under the Transportation Safeguards System. Under DOE Order 474.1, plutonium-238 would be in a safeguard category lower than Categories I and II, which require the use of a safe, secure trailer. However, DOE Order Supplemental Directive AL 5610.14 directs the use of the Transportation Safeguards System for shipments of plutonium-238. The nonirradiated and irradiated targets would carry much less neptunium per shipment, and the form of the neptunium would be less desirable for diversion, so safeguards requirements would be at a lower level.

Although DOE may choose to use the Transportation Safeguards System program for nonirradiated and irradiated target shipments, for the purposes of analysis and flexibility in package selection, this *Consolidation EIS* assumes that commercial vehicles would be used for target shipments.

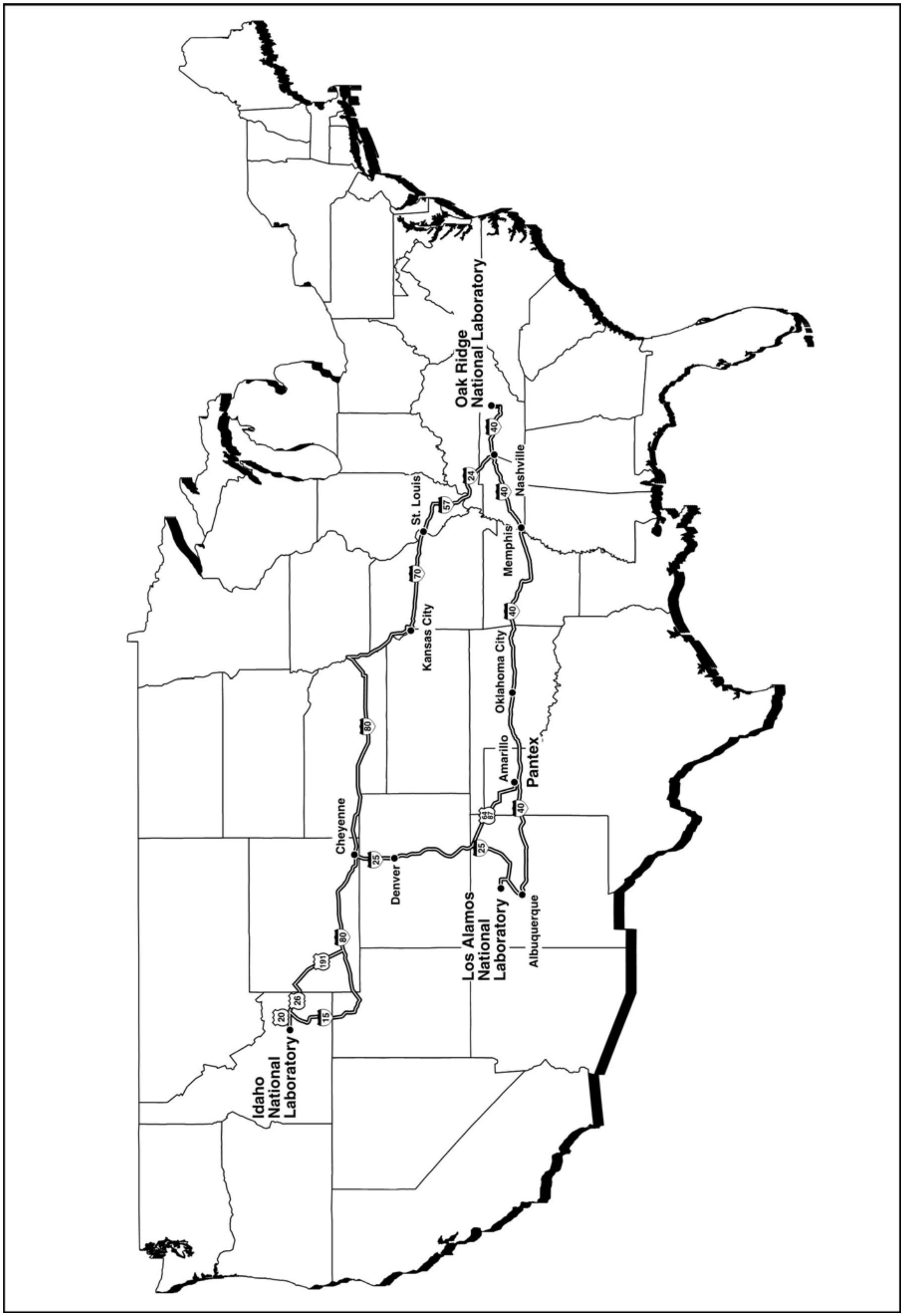

Figure D–2 Analyzed Truck Routes

The SST/SGT is a specially designed component of an 18-wheel tractor-trailer vehicle. While SST/SGT shipments are exempt from DOT regulations (49 CFR Section 173.7[b]), DOE operates and maintains these vehicles in a way that exceeds DOT requirements. Although details of vehicle enhancements and some operational aspects are classified, key characteristics of the SST/SGT system include the following:

- Enhanced structural characteristics and a highly reliable tie-down system to protect cargo from impact;
- Heightened thermal resistance to protect the cargo in case of fire (newer SST/SGT models);
- Established operational and emergency plans and procedures governing the shipment of nuclear materials;
- Various deterrents to prevent unauthorized removal of cargo;
- An armored tractor component that provides courier protection against attack and contains advanced communications equipment;
- Specially designed escort vehicles containing advanced communications equipment and additional couriers;
- 24-hour-a-day real-time communications to monitor the location and status of all SST/SGT shipments via DOE's Security Communication system;
- Couriers, who are armed Federal officers, and who receive rigorous specialized training and are closely monitored through DOE's Personnel Assurance Program;
- Significantly more stringent maintenance standards than those for commercial transport equipment; and
- Periodic appraisals of the Transportation Safeguards System operations by the DOE Office of Defense Programs to ensure compliance with DOE Orders and management directives, and continuous improvement in transportation and emergency management programs.

DOE realizes that the use of SST/SGT vehicles complicates package handling (limited payload mass and size capabilities). ORNL/TM-13526 (Ludwig et al. 1997) provides the following general dimensions for an SST:

Gross vehicle weight rating	36,288 kilograms (80,000 pounds)
Maximum payload	6,169 kilograms (13,600 pounds)
Trailer overall length	18.3 meters (60 feet)
Trailer overall width	259 centimeters (102 inches)
Trailer overall height	4.10 meters (13 feet)
Trailer rear door width	179.1 to 215.9 centimeters (70.5 to 85 inches)
Trailer rear door height	229 centimeters (990 inches)
Trailer floor height above roadway	144 centimeters (56.5 inches)

SGT dimensions are similar. The payload and physical dimensions of the trailer would constrain selection of a cask for transport of the irradiated targets. Therefore, the irradiated and nonirradiated targets would be transported using Type B packages shipped on commercial trailers designed specifically for the packaging being used.

Certified Type B packagings are used to transport various radioactive materials offsite. Neptunium and plutonium are packaged in 9975 and 5320 packagings, respectively. Each 9975 packaging can contain up to 6 kilograms (13.2 pounds) of neptunium-237 (DOE 2004a), and each 5320 packaging can contain up to 357 grams (12.6 ounces) of plutonium-238 (DOE 2004b). The nonirradiated and irradiated targets would be shipped in GE-2000 casks. The gross weight of this package exceeds the load limit on SST/SGTs. Therefore, this cask is transported using a commercial tractor-trailer.

Another source of available and usable plutonium-238 is the milliwatt generator heat sources that are being removed from nuclear weapons as part of the ongoing weapon dismantlement program. A total of 3,200 heat sources are projected to become available between Fiscal Year (FY) 2009 and FY 2022. DOE would transport these heat sources from the Pantex Facility[1] in Texas to INL for storage and future plutonium separation, purification, and up-blending. The need for separation, purification, and upblending (mixing lower purity plutonium-238 with higher purity plutonium-238 to achieve a desired specification purity) is due to the long time period, estimated to be greater than 25 years, since this material was produced. Over time, natural decay of plutonium-238 and concomitant production of other radioisotopes renders the heat source plutonium dioxide unusable without separation, purification, and upblending. These heat sources are encapsulated in a high-strength metal shell that provides high-pressure confinement. They are cylindrical in shape, typically about 1.91 centimeters (0.75 inches) in diameter and height. The plutonium dioxide mass in these heat sources ranges from about 9 to 10 grams, with an original plutonium composition of between 80 and 84 percent plutonium-238. DOE plans to ship these heat sources in a DOE-certified Type B packaging, known as "Mound 1KW," which is constructed for transporting plutonium-238 heat sources in various chemical forms and mechanical configurations (DOE 2004c). The package certificate limits the amount of plutonium-238 to that mass which generates 0.5 kilowatt or less of heat, and limits its transport to three packages per SST/SGT. DOE plans to transport these heat sources in 28 shipments, or 2 shipments annually, between 2009 and 2022.

About 50 kilograms (110 pounds) of neptunium-237 would need to be irradiated to produce 5 kilograms (11 pounds) of plutonium-239. About nine shipments of neptunium targets, each containing about 5.60 kilograms (12.3 pounds) of neptunium-237, are needed to produce 5 kilograms (11 pounds) of plutonium-238. **Table D–2** summarizes the masses of material and the number of shipments required under each alternative.

D.5 Incident-Free Transportation Risks

D.5.1 Radiological Risk

During incident-free transportation of radioactive materials, radiological dose results from exposure to the external radiation field that surrounds the shipping containers. The population dose is a function of the number of people exposed, their proximity to the containers, length of exposure time, and intensity of the radiation field surrounding the containers.

Radiological impacts were determined for crewworkers and the general population during incident-free transportation. For truck shipments, the drivers are the crew of the transport vehicle. For rail shipments, the crew is composed of workers in close proximity to the shipping containers during inspection or classification of railcars. Persons residing within 800 meters (0.5 miles) of the road or railway (off link), persons sharing the road or railway (on link), and persons at stops make up the general population. Exposures of workers who would load and unload the shipments are not included in this analysis, but are included in the occupational exposure estimates for plant workers. Exposures of the inspectors and escorts are evaluated and presented separately.

[1] *Some of the milliwatt generator heat sources could be at LANL. These would be transported to INL using the same packaging method and transport as described for shipments from Pantex.*

Table D–2 Summary of Material Shipments Per Year

Materials	*Package Name*	*Number of Shipments*	*Amount per Package*	*Packages per Shipment*	*Applicable Alternative*	*Total Mass Shipped*
Neptunium oxide	9975	1	5 kilograms of neptunium-237	10	No Action and Consolidation with Bridge	50 kilograms of neptunium [a]
Irradiated targets	GE-2000	7	0.56 kilograms of plutonium-238	1	No Action	~4 kilograms of plutonium
Nonirradiated targets	GE-2000	7	5.6 kilograms of neptunium-237	1	No Action	~39 kilograms of neptunium
Plutonium oxide	5320	1	0.36 kilograms of plutonium-238	14	No Action and Consolidation with Bridge [b]	5 kilograms of plutonium
Plutonium oxide rods	5320	1	0.36 kilograms of plutonium-238	14	No Action and Consolidation with Bridge [b]	5 kilograms of plutonium
Milliwatt generators plutonium heat source	Mound 1KW	2	0.44 kilograms of plutonium-238	2	Consolidation with Bridge and Consolidation	0.88 kilograms of plutonium-238

[a] This amount of neptunium is only required for the first year under the No Action Alternative. Needs for subsequent years are about 6 to 8 kilograms per year of new neptunium, and the rest would come from recycled neptunium in target processing and plutonium separation. Under the Consolidation with Bridge Alternative, a total of 30 kilograms (or one shipment) of neptunium-237 would be needed to produce about 2 kilograms of plutonium-238 per year for 5 years.

[b] Plutonium transport under the Consolidation with Bridge Alternative would be up to 2 kilograms.

Note: To convert from kilograms to pounds, multiply by 2.2046. The program would run for 35 years. Under the No Action Alternative, seven shipments of neptunium targets would be irradiated at ATR annually.

Radiological risks from transporting radioactive materials are estimated in terms of the number of LCFs among the crew and the exposed population. A health risk conversion factor of 0.0006 LCFs per person-rem of exposure was used for both the public and workers (DOE 2003).

Collective doses for the crew and general population were calculated by using the RADTRAN 5 computer code (SNL 2003). The radioactive material shipments were assigned a dose rate based on their radiological characteristics. Offsite transportation of the neptunium, plutonium, and irradiated targets were assumed to be at the regulatory limit of 10 millirem per hour at 2 meters (about 6.6 feet) from the cask or the outer surface of the vehicle (10 CFR 71.47). The nonirradiated targets, shipped in the same shielded cask as the irradiated targets, are assumed to be at one-tenth the regulatory limit.

D.5.2 Nonradiological Risk

The nonradiological risks, or vehicle-related health risks, resulting from incident-free transport could be associated with the generation of air pollutants by transport vehicles during shipment and are independent of the radioactive nature of the cargo. The health endpoint assessed under incident-free transport conditions is the excess latent mortality due to inhalation of vehicle emissions. Unit risk factors for pollutant inhalation in terms of mortality have been generated (Rao et al. 1982). The unit risk factors account for the potential fatalities from emissions of particulates and sulfur dioxide, but they are applicable only to the urban population zone. The emission unit risk factor for truck transport in the urban area is estimated to be 5.0×10^{-8} fatalities per kilometer; for rail transport, it is 2.0×10^{-7} fatalities per kilometer (DOE 2002a). The emergence of considerable data regarding threshold values for various chemical constituents of vehicle exhaust has made linear extrapolation to estimate the risks from vehicle emissions untenable. This calculation has been dropped from RADTRAN in its recent revision (SNL 2003). Therefore, no risk factors are assigned to vehicle emissions in this analysis.

D.5.3 Maximally Exposed Individual Exposure Scenarios

The maximum individual doses for routine offsite transportation were estimated for transportation workers and members of the general population. For truck shipments, three hypothetical scenarios were evaluated to determine the MEI in the general population. These scenarios are:

- A person caught in traffic and located 1.2 meters (4 feet) from the surface of the shipping container for 30 minutes,
- A person at a rest stop/gas station working at a distance of 16 meters (52 feet) from the shipping container, and
- A resident living 30 meters (98 feet) from the highway used to transport the shipping containers.

The hypothetical MEI doses were accumulated over a single year for all transportation shipments. However, for the scenario involving an individual caught in traffic next to a shipping container, the radiological exposures were calculated for only one event because it was considered unlikely that the same individual would be caught in traffic next to all containers for all shipments. For truck shipments, the maximally exposed transportation worker is the driver who was assumed to have been trained as a radiation worker and to drive shipments for up to 2,000 hours per year, or accumulate an exposure of 2 rem per year. The maximum exposure rate for a member of a truck crew as a nonradiation worker is 2 millirem per hour (10 CFR 71.47).

D.6 Transportation Accident Risks and Maximum Reasonably Foreseeable Consequences

D.6.1 Methodology

The offsite transportation accident analysis considers the impact of accidents during the transportation of radioactive materials by truck. Under accident conditions, impacts on human health and the environment could result from the release and dispersal of radioactive material. Transportation accident impacts have been assessed using accident analysis methodologies developed by NRC. This section provides an overview of the methodologies; detailed descriptions of various methodologies are found in the *Radioactive Material Transportation Study* (NRC 1977), *Modal Study* (NRC 1987), and *Reexamination Study* (NRC 2000). Accidents that could potentially breach the shipping container are represented by a spectrum of accident severities and radioactive release conditions. Historically, most transportation accidents involving radioactive materials have resulted in little or no release of radioactive material from the shipping container. Consequently, the analysis of accident risks takes into account a spectrum of accidents ranging from high-probability accidents of low severity to hypothetical high-severity accidents that have a correspondingly low probability of occurrence. The accident analysis calculates the probabilities and consequences from this spectrum of accidents.

D.6.2 Accident Rates

For the calculation of accident risks, vehicle accident and fatality rates were taken from data provided in *State-Level Accident Rates for Surface Freight Transportation: A Reexamination* (Saricks and Tompkins 1999). Accident rates are generically defined as the number of accident involvements (or fatalities) in a given year per unit of travel in that same year. Therefore, the rate is a fractional value, with accident involvement count as the numerator of the fraction and vehicular activity (total travel distance in truck kilometers) as its denominator. Accident rates are generally determined for a multi-year period. For assessment purposes, the total number of expected accidents or fatalities was calculated by multiplying the total shipment distance for a specific case by the appropriate accident or fatality rate.

For truck transportation, the rates presented are specifically for heavy-haul combination trucks involved in interstate commerce (Saricks and Tompkins 1999). Heavy-haul combination trucks are rigs composed of a separable tractor unit containing the engine and one to three freight trailers connected to each other. Heavy-haul combination trucks are typically used for radioactive material shipments. The truck accident rates are computed for each state based on statistics compiled by the Federal Highway Administration, Office of Motor Carriers, from 1994 to 1996. A fatality caused by an accident is the death of a member of the public who is killed instantly or dies within 30 days due to injuries sustained in the accident.

For offsite commercial truck transportation, separate accident rates and accident fatality risks were used for rural, suburban, and urban population zones. The values selected are the mean accident and fatality rates given in *State-Level Accident Rates for Surface Freight Transportation: A Reexamination* (Saricks and Tompkins 1999) under interstate, primary, and total categories for rural, suburban, and urban population zones, respectively. The accident rates are 3.15, 3.52, and 3.66 per 10 million truck kilometers, and the fatality rates are 0.88, 1.49, and 2.32 per 100 million truck kilometers for rural, suburban, and urban zones, respectively.

For the SST/SGT transport, accident and fatality rates given in the *Final Programmatic Environmental Impact Statement for Accomplishing Expanded Civilian Nuclear Energy Research and Development and Isotope Production Missions in the United States, Including the Role of the Fast Flux Test Facility* were used (DOE 2000). Based on operational experience between FY 1984 and FY 1998, the mean probability of an accident requiring towing of the SST/SGT was 0.058 accidents per million kilometers (0.096 accidents per million miles). Since its establishment in 1975, the DOE Transportation Safeguards Division has accumulated more than 24.4 million kilometers (15.2 million miles) of on-the-road experience transporting DOE-owned cargo with no accidents resulting in a fatality or release of radioactive material. DOE used influence factors from *Determination of Influence Factors and Accident Rates for the Armored Tractor/Safe Secure Trailer* (Phillips, Clauss, and Blower 1994) to estimate accident frequencies and fatality rates for rural, urban, and suburban zones (DOE 2000). The accident rates are 4.18, 5.17, and 6.15 per 100 million truck kilometers, and the fatality rates are 0.39, 0.43, and 0.41 per 100 million truck kilometers for rural, suburban, and urban zones, respectively.

D.6.3 Accident Severity Categories and Conditional Probabilities

Accident severity categories for potential radioactive material transportation accidents are described in the *Radioactive Material Transportation Study* (NRC 1977) for radioactive materials in general and in the "Modal Study," (NRC 1987) and the *Reexamination Study* (NRC 2000) for spent fuel. This latter transportation risk study represents a refinement of the *Modal Study*. The methods described in the *Modal Study* and the *Reexamination Study* are applicable to transportation of irradiated targets in a Type B spent fuel cask. The accident severity categories presented in the *Radioactive Material Transportation Study* would be applicable to neptunium and plutonium transport.

The *Radioactive Material Transportation Study* (NRC 1977) originally was used to estimate conditional probabilities associated with accidents involving transportation of radioactive materials. The *Modal Study* and the *Reexamination Study* (NRC 1987, 2000) are initiatives taken by NRC to refine more precisely the analysis presented in the *Radioactive Material Transportation Study* for spent nuclear fuel shipping casks.

Whereas the *Radioactive Material Transportation Study* analysis was primarily performed using best engineering judgments and presumptions concerning cask response, the later studies rely on sophisticated structural and thermal engineering analysis and a probabilistic assessment of the conditions that could be experienced in severe transportation accidents. These results are based on representative spent nuclear fuel casks assumed to have been designed, manufactured, operated, and maintained according to national codes and standards. Design parameters of the representative casks were chosen to meet the minimum test criteria specified in "Packaging and Transportation of Radioactive Material" (10 CFR 71). The study is believed to provide realistic, yet conservative, results for radiological releases under transport accident conditions.

In the *Modal Study* and the *Reexamination Study*, potential accident damage to a cask is categorized according to the magnitude of the mechanical forces (impact) and thermal forces (fire) to which a cask is subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a cask is subjected to forces within a certain range of values is assigned to the accident severity region associated with that range. The accident severity scheme is designed to take into account all potential foreseeable transportation accidents, including accidents with low probability but high consequences and those with high probability but low consequences.

As discussed earlier, the accident consequence assessment considers only the potential impacts of the most severe transportation accidents. In terms of risk, the severity of an accident must be viewed in terms of potential radiological consequences, which are directly proportional to the fraction of the radioactive material within a cask that is released to the environment during the accident. Although accident severity regions span the entire range of mechanical and thermal accident loads, they are grouped into accident categories that can be characterized by a single set of release fractions and are, therefore, considered together in the accident consequence assessment. The accident category severity fraction is the sum of all conditional probabilities in that accident category.

For the accident risk assessment, accident "dose risk" was generically defined as the product of the consequences of an accident and the probability of the occurrence of that accident, an approach consistent with the methodology used by the RADTRAN 5 computer code. The RADTRAN 5 code sums the product of consequences and probability over all accident severity categories to obtain a probability-weighted risk value referred to in this appendix as "dose risk," which is expressed in units of person-rem.

D.6.4 Atmospheric Conditions

Because it is impossible to predict the specific location of an offsite transportation accident, generic atmospheric conditions were selected for the risk and consequence assessments. On the basis of observations from National Weather Service surface meteorological stations at over 177 locations in the United States, on an annual average, neutral conditions (Pasquill Stability Classes C and D) occur 58.5 percent of the time, and stable (Pasquill Stability Classes E and G) and unstable (Pasquill Stability Classes A and B) conditions occur 33.5 and 8 percent of the time, respectively (DOE 2002a). Neutral weather conditions predominate in each season, but most frequently in the winter (nearly 60 percent of the observations).

Neutral weather conditions (Pasquill Stability Class D) compose the most frequently occurring atmospheric stability condition in the United States and are thus most likely to be present in the event of an accident involving a radioactive material shipment. Neutral weather conditions are typified by moderate windspeeds, vertical mixing within the atmosphere, and good dispersion of atmospheric contaminants. Stable weather conditions are typified by low windspeeds, very little vertical mixing within the atmosphere, and poor dispersion of atmospheric contaminants. The atmospheric condition used in RADTRAN 5 is an average weather condition that corresponds to a stability class spread between Class D (for near distance) and Class E (for farther distance).

Accident consequences for the maximum reasonably foreseeable accident (an accident with a likelihood of occurrence greater than 1 in 10 million per year) were assessed under both stable (Class F, with windspeed of 1 meter [3.3 feet] per second) and neutral (Class D, with windspeed of 4 meters [13 feet] per second) atmospheric conditions. These calculations provide an estimate of the potential dose to an individual and a population within a zone, respectively. The individual dose would represent the MEI in an accident under worst-case weather conditions (stable, with minimum diffusion and dilution). The population dose would represent an average weather condition.

D.6.5 Radioactive Release Characteristics

Radiological consequences were calculated by assigning radionuclide release fractions on the basis of the type of radioactive substance, type of shipping container, and accident severity category. The release fraction is defined as the fraction of radioactivity in the container that could be released to the atmosphere in a given severity of accident. Release fractions vary according to material type and the physical or chemical properties of the radioisotopes. Most solid radionuclides are nonvolatile and, therefore, relatively nondispersible.

Representative release fractions were developed for each radioactive material and container type on the basis of DOE and NRC reports (DOE 1994, 1995, 2002b; NRC 1977, 2000). The severity categories and corresponding release fractions provided in the NRC documents cover a range of accidents from no impact (zero speed) to impacts with speed in excess of 193 kilometers (120 miles) per hour onto an unyielding surface. For the irradiated and nonirradiated targets (neptunium-aluminum fuel clad in aluminum), which are similar in construction to the fuels used in ATR or HFIR (uranium-aluminum fuel clad in aluminum), release fractions given in the *Department of Energy Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Final Environmental Impact Statement* (DOE 1995) for the research reactor fuels were used. For the neptunium and plutonium transport in the SST/SGT, release fractions corresponding to *Radioactive Material Transportation Study* (NRC 1977) severity fractions were used (DOE 2000).

D.6.6 Acts of Sabotage or Terrorism

In the aftermath of the tragic events of September 11, 2001, DOE is continuing to assess measures to minimize the risk or potential consequences of radiological sabotage. Acts of sabotage and terrorism have been evaluated for spent nuclear fuel and high-level radioactive waste shipments (DOE 1996, 2002a). The spectrum of accidents considered ranges from direct attack on the cask from afar to hijacking and exploding the shipping cask in an urban area. Both of these actions would result in damaging the cask and its contents and releasing radioactive materials. The fraction of the materials released is dependent on the nature of the attack (type of explosive or weapon used). The sabotage event was assumed to occur in an urbanized area. The accident was assumed to involve a rail-sized cask containing immobilized high-level radioactive waste. The DOE evaluation of sabotage of a rail-size cask containing spent nuclear fuel in the *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada (Yucca Mountain EIS)* calculated a population dose of 17,000 person-rem and an MEI dose (at 140 meters [460 feet]) of 40 rem, causing 9 additional cancer deaths among the population of exposed individuals and increasing the risk of a fatal cancer to the MEI by 2 percent (DOE 2002a). The radioactive materials transported under all alternatives would have lower quantities of the materials used for the above analysis. Therefore, the above estimates of risk bound the risks from an act of sabotage or terrorism involving the radioactive material transported under all alternatives in this *Consolidation EIS*.

D.7 Risk Analysis Results

Per-shipment risk factors have been calculated for the collective populations of exposed persons and for the crew for all anticipated routes and shipment configurations. The radiological risks are presented in doses per shipment for each unique route, material, and container combination. The radiological-dose-per-shipment factors for incident-free transportation are presented in **Table D–3**. To calculate the collective dose, a unit risk factor is developed to estimate the impact of transporting one shipment of radioactive material over each population density zone. The unit risk factors are combined with routing information, such as the shipment distances in various population density zones, to determine the risk for a single shipment (a shipment risk factor) between a given origin and destination. Unit risk factors were developed on the basis of travel on interstate highways and freeways, as required by 49 CFR 171–177 for highway-route-controlled quantities of radioactive material within rural, suburban, and urban population zones by using RADTRAN 5 and its default data. In addition, the analysis assumed that 10 percent of the time, travel through suburban and urban zones would encounter rush-hour conditions, leading to 50 percent of the average speed and doubling traffic volumes. The normal traffic volumes used for truck transport were: 530, 760, and 2,400 vehicles per hour for rural, suburban, and urban zones, respectively (DOE 2002b).

Table D–3 Risk Factors per Shipment of Radioactive Material

Radioactive Material	*Transport Destination (origin)*	*Incident-Free*				*Accident*	
		Crew Dose (person-rem)	*Crew Risk (LCFs)*	*Population Dose (persons rem)*	*Population Risk (LCFs)*	*Radiological Risk (LCFs)*	*Non-radiological Risk (traffic fatalities)*
Neptunium oxide	ORNL (INL)	6.09×10^{-2}	3.65×10^{-5}	4.52×10^{-2}	2.71×10^{-5}	1.75×10^{-10}	2.68×10^{-5}
Irradiated targets	ORNL (INL)	3.47×10^{-2}	2.08×10^{-5}	6.78×10^{-2}	4.07×10^{-5}	9.36×10^{-10}	4.93×10^{-5}
Nonirradiated targets	INL (ORNL)	2.18×10^{-3}	1.31×10^{-6}	4.23×10^{-3}	2.54×10^{-6}	4.02×10^{-13}	4.93×10^{-5}
Plutonium oxide	LANL (ORNL)	5.52×10^{-2}	3.31×10^{-5}	4.75×10^{-2}	2.85×10^{-5}	3.62×10^{-08}	1.90×10^{-5}
Plutonium oxide rods	INL (LANL)	4.35×10^{-2}	2.61×10^{-5}	3.45×10^{-2}	2.85×0^{-5}	2.33×10^{-08}	1.49×10^{-5}
Milliwatt generators plutonium heat source	INL (Pantex)	2.58×10^{-2}	1.55×10^{-5}	1.35×10^{-2}	8.10×0^{-6}	3.14×10^{-09}	1.35×10^{-5}
Milliwatt generators plutonium heat source	INL (LANL)	2.76×10^{-2}	1.66×10^{-5}	1.54×10^{-2}	9.23×0^{-6}	4.48×10^{-09}	1.49×10^{-5}

LCF = latent cancer fatality, ORNL = Oak Ridge National Laboratory, INL = Idaho National Laboratory, LANL = Los Alamos National Laboratory.

Doses are calculated for the crew and public (i.e., people living along the route, pedestrians, and drivers along the route, and the public at rest and at fueling stops). For onsite shipments, the stop dose (doses to the public at rest and refueling stops) is set at zero, because a truck is not expected to stop during shipment that takes less than an hour.

Both the radiological dose risk factor and nonradiological risk factor for transportation accidents are presented in Table D–3. The radiological and nonradiological accident risk factors are provided in terms of potential fatalities per shipment. The radiological risks are in terms of LCFs. For the population, the radiological risks were calculated by multiplying the accident dose risks by the health risk factor of 6×10^{-4} cancer fatalities per person-rem of exposure. As stated earlier (see Section D.6.3), the accident dose is called "dose risk" because the values incorporate the spectrum of accident severity probabilities and associated consequences (e.g., dose). The radiological accident doses are very low because accident severity probabilities (i.e., likelihood of accidents leading to confinement breach of a shipping cask or the SST/SGTs and release of its contents) are very small, and although persons are residing in an 80-kilometer (50-mile) radius of the road, they are generally quite far from the road. Because RADTRAN 5 uses an assumption of a homogeneous population from the road out to 80 kilometers (50 miles), it would greatly overestimate the actual doses. The nonradiological risk factors are nonoccupational traffic fatalities (immediate fatalities) resulting from transportation accidents.

Table D–4 shows the risks of transportation under each alternative. The risks are calculated by multiplying the previously given per-shipment factors by the number of shipments over the duration of the program and, for the radiological doses, by the health risk conversion factors. The values presented in Table D–4 show that the total radiological risks (the product of consequence and frequency) are very small under all alternatives. Note that, under the Consolidation Alternative, irradiated targets would be transported onsite (on a private road between MFC and ATR at INL). Multiple transfers of irradiated and nonirradiated targets between these two locations could occur annually. Because the road is closed to the public, DOE could choose to use a formerly certified Type B cask, and no incident-free transportation risk analysis would be necessary. Worker dose would be included in the handling analysis. No accident analysis is necessary, because potential accidents during transportation would be bounded in frequency and consequence by operational activities and handling accidents. Once the cask is closed for the low speed transportation between the onsite facilities, the likelihood of any foreseeable accident that could expose the cask to conditions severe enough to breach the cask would be very small. The same discussions are also applicable to the onsite transport of these materials at ORNL under the No Action and Consolidation with Bridge Alternatives.

Table D–4 Risks of Transporting Radioactive Materials

Alternative	*Number of Offsite Shipments*	*Kilometers Traveled*	*Incident-Free*				*Accident*	
			Crew		*Population*			
			Dose (person-rem)	*Risk* [a]	*Dose (person-rem)*	*Risk* [a]	*Radiological Risk* [a]	*Non-radiological Risk* [a]
No Action	595 [b]	1.92×10^{6}	14.63	0.009	22.12	0.013	2.32×10^{-6}	0.036
Consolidation	28 [c]	5.26×10^{4}	0.77	0.00046	0.43	0.00026	1.25×10^{-7}	0.00042
Consolidation with Bridge	39 [d]	7.72×10^{4}	1.33	0.0008	0.89	0.000530	2.44×10^{-7}	0.00061

[a] Risk is expressed in terms of latent cancer fatalities, except for nonradiological risk, which refers to the number of accident fatalities.
[b] Number of offsite shipments over 35 years.
[c] These offsite shipments are for the transport of the milliwatt generator heat sources to INL over a 14 year period.
[d] These offsite shipments include both the transport of milliwatt generator heat sources and the bridge time period offsite shipments over the first 5 years.
Note: To convert kilometers to miles, multiply by 0.6214.

Risks to various exposed individuals under incident-free transportation conditions have been estimated for hypothetical exposure scenarios identified in Section D.5.3. The estimated doses to workers, and the public are presented in **Table D–5**. Doses are presented on a per-event basis (person-rem per event), as it is unlikely that the same person would be exposed to multiple events; for those that could have multiple exposures, the cumulative dose could be calculated. The maximum dose to a crewmember is based on the same individual being responsible for driving every shipment for the duration of the campaign. Note that the potential exists for larger individual exposures if multiple exposure events occur. For example, the dose to a person stuck in traffic next to a shipment of irradiated targets for 30 minutes is calculated to be 20 millirem. This is considered a one-time event for that individual.

A member of the public residing along the route would likely receive multiple exposures from passing shipments. The cumulative dose to this resident can be calculated assuming all shipments passed his or her home. The cumulative doses are calculated assuming that the resident is present for every shipment and is unshielded at a distance of 30 meters (about 98 feet) from the route. Therefore, the cumulative dose depends on the number of shipments passing a particular point and is independent of the actual route being considered. The maximum dose to this resident, if all the materials were to be shipped via this route, would be less than 0.01 millirem.

Table D–5 Estimated Dose to Maximally Exposed Individuals During Incident-Free Transportation Conditions

Receptor	*Dose to Maximally Exposed Individual*
Workers	
Crewmember (truck/rail driver)	2 rem per year [a]
Public	
Resident (along the truck route)	5.6×10^{-7} rem per event
Person in traffic congestion	0.02 rem per event per 0.5-hour stop
Person at a rest stop/gas station	3.7×10^{-4} rem per event per hour of stop

[a] Maximum administrative dose limit per year for a trained radiation worker (i.e., truck crewmember) (DOE 1999).

The accident risk assessment and the impacts shown in Table D–4 take into account the entire spectrum of potential accidents, from the fender bender to extremely severe. To provide additional insight into the severity of accidents in terms of the potential dose to an MEI and the public, an accident consequence assessment has been performed for a maximum reasonably foreseeable hypothetical transportation accident with a likelihood of occurrence greater than 1 in 10 million per year. The results, presented in Table D–4, include all conceivable accidents, irrespective of their likelihood.

The maximum reasonably foreseeable offsite transportation accident under the No Action Alternative (probability of occurrence more than 1 in 10 million per year) is a medium-to-high impact with fire accident involving a shipment of irradiated neptunium targets. The accident has a likelihood of occurrence of 1.4×10^{-5}, 3.6×10^{-6}, and 3.2×10^{-7} per year in rural, suburban, and urban zones, respectively. The consequences of such an accident in terms of dose and risk of LCFs to an MEI, an individual standing 100 meters (330 feet) downwind from the accident, and to the population residing within 80 kilometers (50 miles) in the rural, suburban, and urban zones are provided in **Table D–6.** The consequences of such an accident in terms of population dose in the rural, suburban, and urban zones are: 0.019, 0.43, and 3.0 person-rem, respectively. This accident could result in a dose of 0.008 rem to a hypothetical individual exposed to the accident plume for 2 hours at a distance of 100 meters (330 feet), with a corresponding LCF risk of 4.8×10^{-6}. The consequences of such an accident in terms of population dose in the rural, suburban, and urban zones are: 0.019, 0.43, and 3.0 person-rem, respectively.

Under the action alternatives, the maximum reasonably foreseeable offsite transportation accident would not lead to a breach of the transportation package. The consequences of the most severe accident that could breach the transportation vehicle (e.g., SST/SGT) and its contents and release radioactive materials were estimated to have a likelihood of less than 1 in 10 million per year.

Table D–6 Estimated Dose to the Population and to Maximally Exposed Individuals During Most-Severe Accident Conditions

Material and Accident Location		*Population* [a]		*Maximally Exposed Individual* [b]	
		Dose (person-rem)	*Risk (latent cancer fatalities)*	*Dose (rem)*	*Risk (latent cancer fatalities)*
Irradiated targets	Rural	0.019	1.14×10^{-5}	0.008	4.8×10^{-6}
	Suburban	0.43	2.58×10^{-4}	0.008	4.8×10^{-6}
	Urban	3.0	1.8×10^{-3}	0.008	4.8×10^{-6}

[a] Population extends at a uniform density to a radius of 80 kilometers (50 miles). The weather condition was assumed to be Pasquill Stability Class D, with a windspeed of 4 meters per second (9 miles per hour).

[b] The individual is assumed to be 100 meters (300 feet) downwind from the accident and exposed to the entire plume of the radioactive release from a 2-hour high-temperature fire. The weather condition was assumed to be Pasquill Stability Class F, with a windspeed of 1 meter per second (2.2 miles per hour).

D.8 Conclusions

Transportation of any commodity involves a risk to both transportation crewmembers and members of the public. This risk results directly from transportation-related accidents and indirectly from the increased levels of pollution from vehicle emissions, regardless of the cargo. The transportation of certain materials, such as hazardous or radioactive substances, can pose an additional risk due to the nature of the material itself.

All alternatives would require intersite shipments of radioactive materials. Based on the results presented in the previous sections, the following conclusions have been reached (see Tables D–4, D–5, and D–6):

- It is unlikely that transportation of radioactive substances under alternatives presented in this EIS would cause an additional fatality as a result of radiation from either incident-free operations or postulated transportation accidents.

- Nonradiological accident risks (the potential for fatalities as a direct result of traffic accidents) present the greatest risks.

D.9 Long-Term Impacts of Transportation

The *Yucca Mountain EIS* (DOE 2002a) analyzed the cumulative impacts of radioactive material transportation, consisting of impacts of radioactive waste and spent nuclear fuel historical shipments; reasonably foreseeable actions that include transportation of radioactive material; and general radioactive material transportation that is not related to a particular action. The collective dose to the general population and workers was the measure used to quantify cumulative transportation impacts. This measure of impact was chosen because it may be directly related to the LCFs using a cancer risk coefficient. **Table D–7** provides a summary of the total worker and general population collective doses from various transportation activities. The table shows that the impacts of this program are quite small compared with the overall transportation impacts. The total worker collective dose from all types of shipments (historical, EIS alternative, reasonably foreseeable actions, and general transportation) was estimated to be 368,244 person-rem (221 LCFs) for the period 1943 through 2047 (104 years). The total general population collective dose was estimated to be 338,252 person-rem (203 LCFs). The majority of the collective dose for workers and the general population was due to the general transportation of radioactive material. Examples of these activities are shipments of radiopharmaceuticals to nuclear medicine laboratories and shipments of commercial low-level radioactive waste to commercial disposal facilities. The total number of LCFs estimated to result from radioactive material transportation over the period between 1943 and 2047 is 203. Over this same period (104 years), approximately 31 million people would die from cancer, based on 300,000 cancer fatalities per year unrelated to radioactive material transportation. It should be noted that the estimated number of transportation-related LCFs would be indistinguishable from other LCFs, and the transportation-related LCFs are 0.0014 percent of the total number of LCFs.

D.10 Uncertainty and Conservatism in Estimated Impacts

The sequence of analyses performed to generate estimates of radiological risk for transportation includes: (1) determination of the inventory and characteristics, (2) estimation of shipment requirements, (3) determination of route characteristics, (4) calculation of radiation doses to exposed individuals (including estimating of environmental transport and uptake of radionuclides), and (5) estimation of health effects. Uncertainties are associated with each of these steps. Uncertainties exist in the way that the physical systems being analyzed are represented by the computational models; in the data required to exercise the models (due to measurement errors, sampling errors, natural variability, or unknowns caused simply by the future nature of the actions being analyzed); and in the calculations themselves (e.g., approximate algorithms used by the computers).

Table D–7 Cumulative Transportation-Related Radiological Collective Doses and Latent Cancer Fatalities (1943 to 2047)

Category	*Collective Worker Dose (person-rem)*	*Collective General Population Dose (person-rem)*
Transportation Impacts in this *Consolidation EIS*	15 [a]	22 [b]
Other Nuclear Material Shipments		
Historical	330	230
Reasonably foreseeable	21,000	45,000
General transportation (1943 to 2033)	310,000	260,000
General transportation (1943 to 2047)	330,000	290,000
Yucca Mountain EIS (maximum transport) (up to 2047)	17,000	3,000
Total collective dose (up to 2047)	368,244	338,252
Total latent cancer fatalities	221	203

Yucca Mountain EIS = Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada.
[a] Maximum value from this *Consolidation EIS*, Table D–4: No Action Alternative.
[b] Maximum value from this *Consolidation EIS*, Table D–4: No Action Alternative.
Source: DOE 2002a.

In principle, one can estimate the uncertainty associated with each input or computational source and predict the resultant uncertainty in each set of calculations. Thus, one can propagate the uncertainties from one set of calculations to the next and estimate the uncertainty in the final, or absolute, result. However, conducting such a full-scale quantitative uncertainty analysis is often impractical and sometimes impossible, especially for actions to be initiated at an unspecified time in the future. Instead, the risk analysis is designed to ensure, through uniform and judicious selection of scenarios, models, and input parameters, that relative comparisons of risk among the various alternatives are meaningful. In the transportation risk assessment, this design is accomplished by uniformly applying common input parameters and assumptions to each alternative. Therefore, although considerable uncertainty is inherent in the absolute magnitude of the transportation risk under each alternative, much less uncertainty is associated with the relative differences among the alternatives in a given measure of risk.

In the following sections, areas of uncertainty are discussed for the assessment steps enumerated above. Special emphasis is placed on identifying whether the uncertainties affect relative or absolute measures of risk. The reality and conservatism of the assumptions are addressed. Where practical, the parameters that most significantly affect the risk assessment results are identified.

D.10.1 Uncertainties in Material Inventory and Characterization

The inventories and the physical and radiological characteristics are important input parameters in the transportation risk assessment. The potential number of shipments under all alternatives is primarily based on the projected dimensions of package contents, the strength of the radiation field, the heat that must be dissipated, and assumptions concerning shipment capacities. Physical and radiological characteristics are important in determining the material released during accidents and the subsequent doses to exposed individuals through multiple environmental exposure pathways.

Uncertainties in the inventory and characterization are reflected in the transportation risk results. If the inventory is overestimated (or underestimated), the resulting transportation risk estimates are also overestimated (or underestimated) by roughly the same factor. However, the same inventory estimates are used to analyze the transportation impacts of each *Consolidation EIS* alternative. Therefore, for comparative purposes, the observed differences in transportation risks among the alternatives, as given in Table D–4, are believed to represent unbiased, reasonably accurate estimates from current information in terms of relative risk comparisons.

D.10.2 Uncertainties in Containers, Shipment Capacities, and Number of Shipments

The transportation required under each alternative is based in part on assumptions concerning the packaging characteristics and shipment capacities for commercial trucks. Representative shipment capacities have been defined for assessment purposes based on probable future shipment capacities. In reality, the actual shipment capacities may differ from the predicted capacities such that the projected number of shipments and, consequently, the total transportation risk, would change. However, although the predicted transportation risks would increase or decrease accordingly, the relative differences in risks among alternatives would remain about the same.

D.10.3 Uncertainties in Route Determination

Routes have been determined between all origin and destination sites considered in this *Consolidation EIS.* The routes have been determined to be consistent with current guidelines, regulations, and practices, but may not be the actual routes that would be used in the future. In reality, the actual routes could differ from the analyzed ones with regard to distances and total population along the routes. Moreover, because materials could be transported over an extended time starting at some time in the future, the highway infrastructures and the demographics along routes could change. These effects have not been accounted for in the transportation assessment; however, it is not anticipated that these changes would significantly affect relative comparisons of risk among the alternatives considered in this EIS.

D.10.4 Uncertainties in the Calculation of Radiation Doses

The models used to calculate radiation doses from transportation activities introduce a further uncertainty in the risk assessment process. Estimating the accuracy or absolute uncertainty of the risk assessment results is generally difficult. The accuracy of the calculated results is closely related to the limitations of the computational models and to the uncertainties in each of the input parameters that the model requires. The single greatest limitation facing users of RADTRAN, or any computer code of this type, is the scarcity of data for certain input parameters. Populations (off and on link) along the routes, shipment surface dose rates, and individuals residing near the roads are the most uncertain data in dose calculations. In preparing these data, one makes assumptions that the off-link population is uniformly distributed; the on-link population is proportional to the traffic density, with an assumed occupancy of two persons per car; the shipment surface dose rate is the maximum allowed dose rate; and a potential exists for an individual to be residing at the edge of the road. It is clear that not all assumptions are accurate. For example, the off-link population is mostly heterogeneous, and the on-link traffic density varies widely from road to road. Finally, added to this complexity are the assumptions regarding the expected distance between the public and the shipment at a traffic stop, rest stop, or traffic jam and the afforded shielding.

Uncertainties associated with the computational models are reduced by using state-of-the-art computer codes that have undergone extensive review. Because many uncertainties are recognized but difficult to quantify, assumptions are made at each step of the risk assessment process intended to produce conservative results (i.e., overestimate the calculated dose and radiological risk). Because parameters and assumptions are applied consistently to all alternatives, this model bias is not expected to affect the meaningfulness of relative comparisons of risk; however, the results may not represent risks in an absolute sense.

D.11 References

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