APPENDIX E

TRANSPORTATION

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E.1 INTRODUCTION

This appendix summarizes the methods for and results of the analyses of the environmental impacts of radioactive materials transportation using public highways and rail systems. The impacts are presented by alternative and include radiation doses and health effects as follows:

Section E.1 provides general information regarding transportation of radioactive materials that apply to all alternatives studied in this Global Nuclear Energy Partnership (GNEP) Programmatic Environmental Impact Statement (PEIS). This information includes a listing of applicable transportation regulations, methodologies used to assess the environmental impacts due to the transportation of radioactive materials, and a description of the modeling software used in this PEIS.

Section E.2 provides a description of the methodologies and input parameters that apply to the transportation assessment of the domestic programmatic alternatives of this PEIS. The assessment of the domestic programmatic alternatives used generic input parameters in which no specific site identification was assumed. Generic population densities were derived based on one set of data used to analyze the transport of spent nuclear fuel (SNF) across the continental United States.

Section E.3 describes the methodologies and input parameters used to assess the transportation impacts associated with the international initiatives.

E.1.1 Transportation Regulations

The *Hazardous Materials Transportation Act*, as amended (49 U.S.C. 1501 et seq.), directs the U.S. Department of Transportation (DOT) to develop transportation safety standards for hazardous materials, including radioactive materials. Title 49 of the Code of Federal Regulations contains DOT standards and requirements for the packaging, transporting, and handling of radioactive materials for all modes of transportation. In addition, the U.S. Nuclear Regulatory Commission (NRC) regulates design and performance standards for packages that carry radioactive materials (10 CFR Part 71, DOE 2008f).

If shipments are undertaken by private commercial entities, those shipments are subject to regulation by DOT, the NRC, and other entities, as appropriate. If shipments are undertaken by or on behalf of DOE, all DOE shipments would meet or exceed the requirements and standards of DOT and the NRC that apply to comparable commercial shipments, except where there is a determination that national security or another critical interest requires different action. This policy is set forth in DOE Orders 460.1B, *Packaging and Transportation Safety*, 460.2A, *Departmental Materials Transportation and Packaging Management*, and 470.4A, *Safeguards and Security Program*.

E.1.2 Packaging

The regulatory standards for packaging and transporting radioactive materials in 10 CFR Part 71 and 49 CFR Parts 173 to 178 are designed to achieve four primary objectives:

- Protect persons and property from radiation emitted from packages during transportation, by placing specific limitations on the allowable radiation levels.
- Provide proper containment of the radioactive material in the package achieved by packaging design requirements based on performance-oriented packaging integrity tests and environmental criteria.
- Prevent nuclear criticality, an unplanned nuclear chain reaction that may occur as a result of concentrating too much fissile material in one place.
- Provide physical protection against theft and sabotage during transit (DOE 1995e).

The DOT regulates the transportation of hazardous materials in interstate commerce by land, by air, and on navigable water. As outlined in a 1979 Memorandum of Understanding (MOU) with the NRC, the DOT specifically regulates the carriers of radioactive materials and the conditions of transport such as routing, handling and storage, and vehicle and driver requirements (44 FR 38690). The DOT regulates the packaging, labeling, classification, and marking of radioactive material packages. The DOT also has requirements that help reduce transportation impacts and specify the maximum dose rate associated with radioactive material shipments, which help reduce incident-free transportation doses (see 49 CFR Parts 171-180).

The NRC regulates the packaging and transport of radioactive material for its licensees, which includes commercial shippers of radioactive materials. Under the same agreement referred to above, the NRC (in consultation with the DOT) sets the standards for packages containing fissile materials and Type B packages, discussed below. The NRC also establishes safeguards and security regulations to minimize theft, diversion, or attack on certain shipments (10 CFR Parts 71, 73).

Through its management directives, orders, and contractual agreements, DOE ensures the protection of public health and safety by providing oversight and implementation of its transportation standards and orders that are equivalent to those of the NRC and the DOT. DOE has the authority to certify DOE-owned packages. DOE may design, procure, and certify its own packages, for use by DOE and its contractors, if the packages provide for a level of safety that is equivalent to that provided in 10 CFR Part 71.

Radioactive materials are transported in the following types of packages. The amount of radioactivity determines which package must be used.

- **Excepted Packages:** Excepted packages are used to transport materials with extremely low levels of radioactivity and must meet only general design requirements.
- **Industrial Packages:** Industrial packages are used to transport materials that present a limited hazard to the public and environment. Examples include contaminated equipment and radioactive waste solidified in materials such as concrete.

- **Type A Packages:** Type A packages are used to transport radioactive materials with higher concentrations of radioactivity such as low-level waste (LLW). Type A packages are designed to retain their radioactive contents in normal transport. Under normal conditions, a Type A package must withstand:
  - Hot (158°F [70°C]) and cold (-40°F [-40°C]) temperatures
  - Pressure changes of 3.6 pounds per square inch (lbs/in^2) (25 kilopascal [kPa])
  - Normal vibration experienced during transportation
  - Simulated rainfall of 2 inch (in) (5 centimeter [cm]) per hour for 1 hour
  - Free drop from 1 to 3.3 feet (ft) (0.3 to 1 meter [m]), depending on the package weight
  - Corner drop test
  - Compression test
  - Impact of a 13.2 pounds (lbs) (6 kilograms [kg]) steel cylinder with rounded ends dropped from 3.3 ft (1 m) onto the most vulnerable surface of the cask (10 CFR Part 71)

- **Type B Packages:** Type B packages are used to transport materials with radioactivity levels higher than those allowed for Type A packages. Type B packages are designed to retain their radioactive contents in normal and accident conditions (49 CFR Part 173). In addition to the normal conditions outlined above, under accident conditions a Type B package must withstand:
  - Free drop from 30 ft (9 m) onto an unyielding surface in a way most likely to cause damage to the cask
  - For some low-density, light-weight packages, a dynamic crush test consisting of dropping a 1,100 lbs (500 kg) mass from 30 ft (9 m) onto the package resting on an unyielding surface
  - Free drop from 40 in (1 m) onto the end of a 6 in (15 cm) diameter vertical steel bar
  - Exposure for not less than 30 minutes to temperatures of 1,475°F (800°C)
  - For all packages, immersion in at least 50 ft (15 m) of water for 8 hours
  - For fissile material packages, immersion in at least 3 ft (0.9 m) of water for 8 hours in an orientation most likely to result in leakage (10 CFR Part 71)
  - Immersion tests at a depth of at least 660 ft (200 m) of water for 1 hour to evaluate undamaged package performance

Compliance with these requirements is demonstrated by using computer modeling techniques, or full-scale or scale-model testing of casks (DOE 1995e).

E.1.3 Emergency Management

States and tribes along shipping routes are primarily responsible for protecting the public and the environment in their jurisdictions. If an emergency involving a DOE radioactive materials shipment occurs, an incident command will be established based on the procedures and policies of the state, tribe, or local jurisdiction. If requested by civil authorities, DOE will provide technical advice and assistance including access to teams of experts in radiological monitoring and related technical areas. DOE staffs eight Regional Coordinating Offices 24 hours a day, 365 days a year with teams of nuclear engineers, health physicists, industrial hygienists, public affairs specialists, and other professionals.

The Department of Homeland Security (DHS) coordinates the overall Federal Government response to radiological Incidents of National Significance in accordance with Homeland Security Presidential Directive-5 (HSPD-5) (White House 2003) and the National Response Framework (DHS 2008). Based on HSPD-5 criteria, an Incident of National Significance is an actual or potential high-impact event that requires a coordinated and effective response by an appropriate combination of Federal, state, local, tribal, nongovernmental, or private-sector entities to save lives and minimize damage, and to provide the basis for long-term community recovery and mitigation activities (DOE 2008f).

In HSPD-5, the President designates the Secretary of Homeland Security as the principal Federal official for domestic incident management and empowers the Secretary to coordinate federal resources used in response to terrorist attacks, major disasters, or other emergencies in specific cases. The Directive establishes a single, comprehensive National Incident Management System that unifies Federal, state, territorial, tribal, and local lines of government into one coordinated effort. This system encompasses much more than the Incident Command System, which is nonetheless a critical component of the National Incident Management System. That system also provides a common foundation for training and other preparedness efforts, communicating and sharing information with other responders and with the public, ordering resources to assist with a response effort, and integrating new technologies and standards to support incident management. The Incident Command System uses as its base the local first responder protocols; that use does not eliminate the required agreements and coordination among all levels of government (DOE 2008f).

In HSPD-5, the President directed the development of the new National Response Framework to align federal coordination structures, capabilities, and resources into a unified approach to domestic incident management. The Framework is built on the template of the National Incident Management System and provides a comprehensive, all-hazards approach to domestic incident management. All Federal departments and agencies must adopt the National Incident Management System and use it in their individual domestic incident management and emergency prevention, preparedness, response, recovery, and mitigation activities, as well as in support of all actions taken to assist state or local entities (DOE 2008f).

DOE supports the DHS as the coordinating agency for incidents that involve the transportation of radioactive materials by or for DOE. DOE is otherwise responsible for the radioactive material, facility, or activity in the incident. DOE is part of the Unified Command, which is an application of the Incident Command System used when there is more than one agency with incident jurisdiction or when incidents cross political jurisdictions. DOE coordinates the Federal radiological response activities as appropriate. Agencies work together through the designated members of the Unified Command, often the senior person from agencies or disciplines that participate in the Unified Command, to establish a common set of objectives and strategies (DOE 2008f).

DOE, as the transporter of radiological material, would notify state and tribal authorities and the Homeland Security Operations Center. The Department of Homeland Security and DOE coordinate federal response and recovery activities for the radiological aspects of an incident. DOE reports information and intelligence in relation to situational awareness and incident management to the Homeland Security Operations Center.

DHS and DOE are responsible for coordination of security activities for federal response operations. While spent nuclear fuel and high-level radioactive waste shipments are in transit, state, local, and tribal governments could provide security for a radiological transportation incident that occurred on public lands. The Department of Homeland Security, with DOE as the coordinating agency, approves issuance of all technical data to state, local, and tribal governments.

DOE maintains national and regional coordination offices at points of access to federal radiological emergency assistance. Requests for Radiological Assessment Program teams go directly to the DOE Emergency Operations Center in Washington, D.C. If the situation requires more assistance than a team can provide, DOE alerts or activates additional resources. DOE can respond with additional resources including the Aerial Measurement System to provide wide-area radiation monitoring and Radiation Emergency Assistance Center/Training Site medical advisory teams. Some participating federal agencies have radiological planning and emergency responsibilities as part of their statutory authority, as well as established working relationships with state counterparts. The monitoring and assessment activity, which DOE coordinates, does not alter these responsibilities but complements them by providing coordination of the initial federal radiological monitoring and assessment response activities.

The Department of Homeland Security and DOE, as the coordinating agency, oversee the development of Federal Protective Action Recommendations. In this capacity, the departments provide advice and assistance to state, tribal, and local governments, which can include advice and assistance on measures to avoid or reduce exposure of the public to radiation from a release of radioactive material and advice on emergency actions such as sheltering and evacuation.

State, local, and tribal governments are encouraged to follow closely the *National Response Framework* (DHS 2008), the Nuclear/Radiological Incident Annex, and the National Incident Management System protocols and procedures. As established, all federal, state, local, and tribal responders agree to and follow the Incident Command System (DOE 2008f).

E.1.4 Safeguards and Security Regulatory Environment

The risk of sabotage or other intentional destructive acts during the transport of nuclear materials is controlled and regulated by safeguards and security requirements, domestically and internationally, as well as by export controls for international shipments. The regulations and guidance of interest for transportation of nuclear materials are listed below.

U.S. Nuclear Regulatory Commission

10 CFR Part 71: Packaging and Transportation of Radioactive Material
10 CFR Part 73: Physical Protection of Plants and Materials

10 CFR Part 74: Material Control and Accounting of Special Nuclear Material
10 CFR Part 110: Export and Import of Nuclear Equipment and Material

U.S. Department of Transportation

49 CFR Part 172: Hazardous Materials Table … and Training Requirements
49 CFR Part 173: Shippers—General Requirements for Shipments and Packaging
49 CFR Part 174: Carriage by Rail
49 CFR Part 175: Carriage by Aircraft
49 CFR Part 176: Carriage by Vessel
49 CFR Part 177: Carriage by Public Highway
49 CFR Part 178: Specifications for Packagings
49 CFR Part 179: Specifications for Tank Cars
49 CFR Part 180: Continuing Qualification and Maintenance of Packagings

U.S. Department of Energy

10 CFR Part 810: Assistance to Foreign Atomic Energy Activities
DOE-Policy-470: Integrated Safeguards and Security Management (ISSM) Policy

U.S. Department of Commerce

15 CFR Parts 730 to 744: Export Administration Regulations (EAR)

International Agencies

Amended Convention on the Physical Protection of Nuclear Material United Nations Security Council Resolution (UNSCR) 1540
International Atomic Energy Agency Information Circular (IAEA INFCIRC)/153: The Structure and Content of Agreements between the Agency and States required in connection with the Treaty on Non-Proliferation of Nuclear Weapons
IAEA INFCIRC/540: Model Protocol Additional to the Agreement(s) between States and the IAEA for the Application of Safeguards
IAEA-TS-R-1: Regulations for the Safe Transport of Radioactive Material
IAEA-INFCIRC/225: The Physical Protection of Nuclear Material and Nuclear Facilities

E.1.5 Transportation Routes

DOE used the TRAGIS computer program (Johnson and Michelhaugh 2003) to identify the generic rail and truck routes used in the analysis. TRAGIS is a Web-based geographic information system transportation routing computer code. The TRAGIS rail network is developed from a 1-to-100,000-scale rail network derived from the United States Geological Survey digital line graphs. This network currently represents more than 150,000 mi (240,000 km) of rail lines in the continental United States and has over 28,000 segments (links) and over 4,000 intersections (nodes). All rail lines with the exception of industrial spurs are included. The rail network includes nodes for nuclear reactor sites, DOE sites, and military bases that have rail access. The rail network has been extensively modified and is revised on a regular schedule to reflect rail line abandonment, company mergers, short line spin-offs, and new rail construction.

The TRAGIS computer code predicts highway routes for transporting radioactive materials within the United States. The TRAGIS database is a computerized road atlas that currently describes approximately 240,000 mi (390,000 km) of roads. Complete descriptions of the interstate highway system, U.S. highways, most of the principal state highways, and a number of local and community highways are identified in the database.

The TRAGIS computer code calculates routes that maximize the use of interstate highways. This feature allows the user to determine routes for shipment of radioactive materials that conform to the DOT regulations, as specified in 49 CFR Part 397. The calculated routes conform to applicable guidelines and regulations and represent routes that could be used. The routes represent a reasonable prediction of future routes, or are typical of what would be used in the period of study. The code is updated periodically to reflect current road conditions and has been benchmarked against reported mileages and observations of commercial truck firms (Johnson and Michelhaugh 2003).

For all routes traveled by legal-weight truck and heavy-haul truck (inter-modal transfer vehicle used to transport rail SNF casks), the model assumed that highway route-controlled quantities of radioactive materials (HRCQ) carriers would be used, as specified by 49 CFR 397.101. The representative routes for HRCQ carriers selected by TRAGIS are mostly interstate highways or large U.S. highways.

To calculate rail routes, the TRAGIS computer program uses rules that are designed to simulate routing practices that have been historically used by railroad companies in moving regular freight and dedicated trains in the United States. The basic rule used to calculate rail routes causes the program to attempt to identify the shortest route from an origin to a destination. Another rule used in the program biases the lengths of route segments that have the highest density of rail traffic to make these segments appear, for purposes of calculation, to be shorter. The effect of the bias is to prioritize selection of routes that use railroad main lines, which have the highest traffic density. As a general rule, routing along the high traffic lines replicates railroad operational practices. A third rule constrains the program to select routes used by an individual railroad company to lines the company owns or over which has permission to operate. This rule ensures the number of interchanges between railroads that the TRAGIS computer program calculates for a route is correct. The number of interchanges between railroads is a significant consideration when determining a realistic and representative route.

Another rule used in the TRAGIS computer program to calculate a rail route determines the sequence of different railroad companies whose rail lines would be linked to form the route. Because a delay and additional operations are involved in transferring a shipment (interchanging) from one railroad to another, in order to provide efficient service, railroads typically route shipments to minimize the number of interchanges that occur. Reducing the number of interchanges also tends to reduce the time a shipment is in transit. This practice is simulated in the TRAGIS computer program by imposing a penalty for each interchange that is identified for a route. The interchange penalties cause the TRAGIS computer program to increase the calculated length of routes when more than one railroad company's lines are linked. As a consequence, the algorithm used in the TRAGIS computer program to identify routes that have the least apparent length gives advantage to routes that also have the fewest interchanges between railroads and the fewest involved railroad companies.

Last, a rule in the TRAGIS computer program is designed to simulate the commercial behavior of railroad companies to maximize their portion of revenues from shipments. The effect of this behavior is that routing is often affected by originating railroads, who control the selection of routes on their lines to realize as much of a shipment's revenue as possible. The result is that originating railroads transport shipments as far as possible (in the direction of the destination) on their systems before interchanging the shipments with other railroads. This behavior is simulated in the TRAGIS computer program by imposing a bias on the length of the originating railroad's lines to give the railroad an advantage when calculating a route. In evaluating the length of the route, the model treats 1 mile of travel on the originating railroad as being "less" than 1 mile on other railroads (DOE 2008f).

E.1.6 Shipments

Radioactive material shipments associated with the proposed alternatives are assumed to be transported by truck, rail, or barge modes of transport. At this time, insufficient data exist to determine what fraction of shipments would be shipped by either transport mode.

Several types of containers were assumed to be used to transport the radioactive waste evaluated in this PEIS. In this transportation assessment, a shipment is defined as the amount of waste transported on a single truck or a single train voyage. The number of railcars per shipment is provided in each campaign description provided below.

E.1.7 Loading Operations

Loading operations typically represent the largest exposure impacts involved with the transportation of nuclear materials. As in the *Final Supplemental 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* (hereafter Yucca Mountain SEIS) (DOE 2008f), DOE assumed that loading operations would require a staff of 13 workers, working 2.3 and 2.5 shift-days for pressurized water reactor (PWR) and boiling water reactor (BWR) casks respectively. Loading truck casks would require 1.3 and 1.4 shift-days for PWR and BWR casks, respectively (DOE 2008f). Personnel requirements and duration of loading operations were estimated for other material types based on the number and types of containers used for each shipment.

E.1.8 Incident-Free Transportation

Radiological dose during normal, incident-free transportation of radioactive materials would result from exposure to the external radiation from the shipping containers. The dose to a receptor is a function of proximity to the radiation source, exposure time and the intensity (source strength) of the radiation.

Consistent with methods of analysis for DOE and NRC operations, most packages were assumed to have the regulatory maximum exposure rate of 10 millirem per hour (mrem/hr) at a distance of 6.6 ft (2 m) from the source. Although this assumption is conservative, it provides a metric decision makers can use to compare the impacts of the different alternatives. For those materials known to generate much lower external exposure rates, lower (but still conservative) rates were assumed. A more detailed description of the assumptions concerning the external exposure rates of transportation containers is provided in the programmatic alternatives discussion in Section E.2.

Table E.1.8-1 provides the suggested vehicle speeds for truck and rail transport for use in RADTRAN analysis as provided in Neuhauser et al. (2003) and Chen et al. (2002). The vehicle speed is used in the incident-free portion of the risk assessment. In conjunction with the distance traveled, the vehicle speed determines the amount of time the transportation crew, the on-link population and the off-link population are exposed to external radiation from the shipping package.

TABLE E.1.8-1—*RADTRAN Suggested Vehicle Speeds*

Population Zone	Truck Speed [mph (km/h)]	Rail Speed [mph (km/h)]
Rural	55 (88.49)	40 (64.37)
Suburban	25 (40.25)	25 (40.25)
Urban	15 (24.16)	15 (24.16)

Source: Neuhauser et al. 2003, Chen et al. 2002

E.1.8.1 *Worker and General Populations*

Radiation doses were determined for workers, including vehicle crews, and the general population from normal, incident-free transportation. The truck crew was the vehicle drivers. For rail shipments, the crew was defined as workers in close proximity to the shipping containers during inspection or classification of railcars. The general population were the individuals within 2,625 ft (800 m) of the road or railway (off-link), sharing the road or railway (on-link), and at stops. Collective doses for the crew and general population were calculated using the RADTRAN 5.6/RADCAT 2.3 computer codes (Weiner et al 2006).

The scenarios for worker and public populations analyzed in this PEIS are similar to those provided 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* (hereafter Yucca Mountain FEIS) (DOE 2002i) and the Yucca Mountain SEIS (DOE 2008f). These scenarios are consistent with other DOE and NRC NEPA analyses.

For the worker populations, the following scenarios were analyzed:

- An inspector working at a distance of 3.3 ft (1 m) from the rail or truck container. It was assumed that this inspector would be exposed to the SNF casks for 1 hour per cask. For other shipping configurations, it was assumed that an inspector would be exposed to each trailer for 1 hour (Jason Technologies 2001).

- A truck driver and passenger, serving as an escort, that would be expected to drive radioactive shipments for 1,000 hours (hr) per year (yr) and unload shipments for 1,000 hr/yr (Jason Technologies 2001, BMI 2007).
- A rail yard worker working at a distance of 33 ft (10 m) from the shipping container for 2 hours.

For rail shipments, the following scenarios for members of the public were considered:

- A resident living 98 ft (30 m) from the rail line where the shipping container was being transported.
- A resident living 656 ft (200 m) from a rail stop where the shipping container was sitting for 20 hours.

For truck shipments, the three scenarios for members of the public were:

- A person caught in traffic and located 4 ft (1.2 m) away from the surface of the shipping container for 1 hour;
- A service station worker working at a distance of 66 ft (20 m) from the shipping container for 1 hour;
- Area residents near the truck stop/service station. The resident population included those that would live within a distance 0.5 mile (mi) (0.8 kilometer [km]) of the stop;
- A resident living 98 ft (30 m) from the highway used to transport the shipping container. This population is considered to be "Nearby Residents."

The assumed frequency of rail and truck stops in this PEIS is consistent with those used in the Yucca Mountain FEIS and SEIS analyses. Two-hour rail stops were assumed to occur at 170-mi (277-km) intervals, or a rate of 0.012 hr/mi (0.0072 hr/km) (BMI 2007). Truck stops were assumed to occur at a rate of 0.018 hr/mi (0.011 hr/km) (Jason Technologies 2001).

Dose to maximally exposed individuals (MEI) and impacts were estimated for the cumulative operations of the alternatives analyzed. For the scenario involving an individual caught in traffic next to a truck, 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 maximum exposed transportation worker is the driver who was assumed to drive shipments for up to 1,000 hours per year. In the maximum exposed individual scenarios, the exposure rate for the shipments depended on the type of waste being transported. External exposure rates for the transportation packages are provided in Table 2.2.2-1. The different container exposure rates yielded a range of calculated exposure impacts during loading/handling and in-transit shipments. The maximum exposure rate for the truck driver was 2 mrem/hr (10 CFR 71.47[b][4]).

E.1.8.2 *Incident-Free Exposure to Escorts*

Transporting SNF and other selected radioactive materials requires the use of physical security and other escorts for the shipments. Regulations require that at least two individuals serve as escorts for truck shipments traveling through highly populated, urban areas (10 CFR 73.37). At least one of the escorts is required in a vehicle separate from the shipment vehicle. For rail shipments in urban areas, at least two escorts are required in order to maintain visual surveillance of a shipment from a railcar that accompanies a cask car.

For legal-weight truck shipments, the analysis assumed that a second driver, a member of the vehicle crew, serves as an escort in all areas. The analysis assigned a second escort assuming this escort would occupy a vehicle that followed or led the transport vehicle by at least 197 ft (60 m). The analysis assumed that the dose rate at a location 6.5 ft (2 m) behind the vehicle would be 10 mrem/hr, which is the limit allowed by the DOT regulations (49 CFR 173.441).

Using this information, the analysis used the RISKIND computer code to calculate a dose rate of 0.11 mrem/hr for the escort located 197 ft (60 m) behind the transport vehicle (Yuan et al. 1995). The value for an escort vehicle ahead of the transport vehicle would be lower. Because the dose rate in the occupied crew area of the transport vehicle would be less than 2 mrem/hr, the dose rate 6.5 ft (2 m) in front of the vehicle would be much less than 10 mrem/hr, the value assumed for a location 6.5 ft (2 m) behind the vehicle. The value of 2 mrem/hr in normally occupied areas of transport vehicles is the maximum allowed by the DOT regulations (49 CFR 173.441). This exposure analysis for escorts follows methods used in the Yucca Mountain FEIS and Yucca Mountain SEIS assessments (Jason Technologies 2001, BMI 2007).

For rail shipments, the escorts were assumed to be 98 ft (30 m) away from the shipping cask. This is due to the length of a buffer car 50 ft (15 m), the normal separation between cars (6.5 ft [2 m] for two cars), the distance from the end of a cask to the end of the rail car (16.5 ft [5 m]), and the assumed distance from the escort car's near end to the occupants (nearly 33 ft [10 m]). Using the assumed dose rate of 10 mrem/hr at a distance of 6.5 ft (2 m) from the cask, RISKIND calculated an estimated dose rate of 0.46 mrem/hr for the occupied area of the escort car. Two-hour stops were assumed to occur every 170 mi (277 km) (BMI 2007). Visual surveillance must be maintained at all rail yard transfers. Escorts would be present in the escort car from the time the train was assembled at the generator site until it reached its final destination.

E.1.8.3 *Nonradiological Vehicle Emissions*

Incident-free nonradiological vehicle emission fatalities were estimated using unit risk factors. These fatalities would result from exhaust and fugitive dust emissions from highway and rail traffic and are associated with 10-micrometer particles. The nonradiological unit risk factors were adopted from the transportation analysis conducted for the Yucca Mountain FEIS (DOE 2002i). The unit risk factors used in this analysis are 1.5×10^{-11} and 2.6×10^{-11} fatalities per kilometer per persons per square kilometer (km^2) for diesel truck and rail modes of transport respectively (Jason Technologies 2001).

E.1.9 Transportation Accidents

The offsite transportation accident analysis considers the impacts of accidents during the transportation of materials by truck or rail. Under accident conditions, impacts to human health and the environment may result from the release and dispersal of radioactive material. Transportation accident impacts have been assessed using accident analysis methodologies developed by the NRC.

This section provides an overview of the methodologies (NRC 1977b, Fischer et al. 1987, NRC 2000a). Accidents, some of which could potentially breach the shipping container, are represented by a spectrum of accident severities and releases of radioactive material. 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. This accident analysis calculates the risks and consequences from this spectrum of accidents.

Two types of analyses were performed. An accident risk assessment was performed that takes into account the probabilities and consequences of a spectrum of potential accident severities (NRC 1977b, Fischer et al. 1987, NRC 2000a). For the spectrum of accidents considered in the analysis, accident consequences in terms of collective dose to the population within 50 mi (80 km) were multiplied by the accident probabilities to yield collective dose risk using the RADTRAN 5.6/RadCat 2.3 computer codes (Weiner et al. 2006).

The impacts for specific alternatives were calculated in units of dose and collective dose. Impacts are further expressed in terms of estimated latent cancer fatalities (LCF). Dose estimates are converted to LCFs using a conversion factor of 6×10^{-4} LCF per person-rem (DOE 2002h).

E.1.9.1 *Transportation Accident Rates*

For calculating accident risks and consequences, state-specific accident rates were taken from data provided in Saricks and Tompkins (1999) for rail, barge, and heavy combination trucks. The rates, provided in Saricks and Tompkins, are based on state-specific accident and fatality rate data for 1994 to 1996. Subsequent studies by the Federal Motor Carrier Safety Administration found that accidents were under-reported by approximately 39 percent and fatalities were under-reported by approximately 36 percent (UMTRI 2003). To account for the under-reporting, DOE increased the state-specific truck and fatality accident rates from Saricks and Tompkins by factors of 1.57 and 1.64, respectively, in its analysis for the Yucca Mountain SEIS (DOE 2008f). For analysis of truck shipments, these multipliers also were used in this PEIS. For cases where generic routing characteristics were assumed, the 1.57 and 1.64 factors were applied to the U.S. average accident and fatality rates, respectively.

E.1.9.2 *Conditional Probabilities and Release Fractions*

Accident severity categories for potential radioactive waste transportation accidents are described in three NRC reports:

- *Final Environmental Impact Statement on the Transportation of Radioactive Material by Air and Other Modes* (hereafter NUREG-0170) (NRC 1977b) for radioactive waste in general
- *Shipping Container Response to Severe Highway and Railway Accident Conditions,* also known as the Modal Study (Fischer et al. 1987)
- *Reexamination of Spent Fuel Shipment Risk Estimate,* (NRC 2000a)

The second and third reports address only SNF. The Modal Study represents a refinement of the NUREG-0170 methodology, and the reassessment analysis, *Reexamination of Spent Fuel Shipment Risk Estimates* (NRC 2000a), which compares more recent results to NUREG-0170, represents a further refinement of both studies. This later reference was the basis for the conditional probabilities and release fractions used in this analysis.

Reexamination of Spent Fuel Shipment Risk Estimates (NRC 2000a) represents the severe accident environment as a matrix, with one dimension as the temperature of the radioactive material and the other the velocity of impact onto an unyielding surface. The matrix contains 19 cases for the truck accidents and 21 cases for rail accidents. The unique feature of the most recent analysis is the specification of a fire-only case. The result is ultimately reduced to a conditional probability of occurrence for each accident case or category, and a set of radionuclide release fractions for each accident case or category.

E.1.9.3 *Severe Transportation Accidents*

In addition to analyzing the radiological and nonradiological risks of transporting SNF and high-level waste (HLW), DOE assessed the consequences of severe transportation accidents. Severe transportation accidents with a frequency of approximately 1×10^{-7} per year are known as maximum reasonably foreseeable transportation accidents (MRFA). According to DOE guidance, accidents that have a frequency of less than 1×10^{-7} rarely need to be examined (DOE 2002d).

The analysis was based on the 21 rail accident severity categories identified in *Reexamination of Spent Fuel Shipment Risk Estimates* (NRC 2000a). Each of the 21 accident cases has an associated conditional probability of occurrence (NRC 2000a). Combining the conditional probabilities analyzed in the domestic programmatic alternatives, only Cases 4 and 20 of the document have occurrence frequencies greater than 1×10^{-7} per year, with expected annual frequencies of 5×10^{-6} and 3×10^{-6} respectively (NRC 2000a).

The Case 20 event is a long-duration high-temperature fire event that engulfs the entire cask. The event is assumed to last many hours (NRC 2000a). Case 20 was estimated to have the higher consequences and was thus assumed to be the maximum reasonably foreseeable transportation accident.

Case 4 assumes a moderate-speed impact (30 to 60 miles per hour [48 to 97 kilometers per hour]) into a hard surface such as granite, severe enough to cause failure of casks seals. The impact would be followed by an engulfing fire lasting from 0.5 hour to a few hours (NRC 2000a).

Rail shipments were estimated to have higher accident impacts given the higher material inventories per shipment. The PWR light water reactor (LWR) SNF case is analyzed because the maximum load is larger than the BWR (5.0 metric tons heavy metal [MTHM]/cask compared to 4.8 MTHM/cask). The following assumptions, parallel to those provided in the Yucca Mountain SEIS, were made in analyzing the impacts of the maximum reasonably foreseeable accident scenarios:

- A release height of the plume of 33 ft (10 m) for fire and impact-related accidents. In the case of an accident with fire, a 33 ft (10 m) release height with no plume rise from the buoyancy of the plume due to fire conditions would yield higher estimates of consequences than accounting for the buoyancy of the plume from the fire.
- A breathing rate for individuals of 3.67×10^5 cubic feet (ft^3) (1.04×10^4 cubic meters [m^3]) per year (Neuhauser et al. 2003).
- A short-term exposure to airborne contaminants of 2 hours.
- A long-term exposure time to contamination deposited on the ground for 1 year with no interdiction or cleanup (BMI 2007).
- Low wind speeds and stable atmospheric conditions (a wind speed of 2 m/hr [0.89 m/s] and Class F stability). The atmospheric concentrations estimated from these conditions would be exceeded only 5 percent of the time.

DOE used the RISKIND 2.0 code (Yuan et al. 1995) to estimate the radiation doses for the inhalation, groundshine[1], immersion, and re-suspension pathways.

The analysis assumed that the severe transportation accidents could occur anywhere. Generally, in transportation analyses, population densities in rural areas are assumed to range from 0 to 139 people per km^2. Consistent with Yucca Mountain FEIS and SEIS analyses, DOE based the analysis for a rural area on a population density of six people per km^2. For analysis of the Yucca Mountain Project transportation impacts, DOE estimated the population density in an urban area by identifying the 20 urban areas in the United States with the largest populations using 2000 census data, determining the population density in annular rings around the center of each urban area, escalating these population densities to 2067, and averaging the population densities in each successive annular ring. These values were assumed for the maximum reasonably foreseeable impact assessment for this PEIS and are the same values assumed in the Yucca Mountain Final SEIS analyses. The values are provided in Table E.1.9.3-1.

TABLE E.1.9.3-1—*Population Density in Urban Areas*

Annular Distance (mi)	Population Density (/mi^2 [/km^2])
0 to 5 (0 to 8.05 km)	12,980 (5,012)
5 to 10 (8.05 to 16.09 km)	7,656 (2,956)
10 to 15 (16.09 to 24.14 km)	5,470 (2,112)
15 to 20 (24.14 to 32.19 km)	3,476 (1,342)
20 to 25 (32.19 to 40.23 km)	2,330 (899)
25 to 50 (40.23 to 80.47 km)	774 (299)

Source: DOE 2008f

The State of Nevada provided analyses in response to a previous document prepared by DOE proposing similar transportation modes and routes, and utilizing similar analytical methods. The State of Nevada indicated that the consequences of severe transportation accidents would be much higher than those resulting from the accident analysis preformed by DOE. These comments and DOE's response can be found in the *Final EIS for Geological Repository for the Disposal of SNF and High Level Radioactive Waste at Yucca Mountain in Nye County, Nevada* (DOE 2002i). As an example, the State estimated that a rail accident in an urban area could result

[1] Groundshine is defined as gamma radiation emitted from radioactive materials deposited on the ground.

in 13 to 40,868 LCFs in the exposed population while DOE estimated that about 9 LCFs would occur in the exposed population.

The State estimated these consequences using computer programs that DOE developed and uses. However, the state's analysis used values for parameters that would be at or near their maximum values. DOE guidance for the evaluation of accidents in environmental impact statements (DOE 2002d) specifically cautions against the evaluation of scenarios for which conservative (or bounding) values are selected for multiple parameters because the approach yields unrealistically high results due to built-in conservatism in the model.

DOE's approach to accident analysis estimates the consequences of severe accidents having a frequency as low as 1×10^{-7} per year (1 in 10 million) (DOE 2002d) using realistic yet cautious methods and data. DOE believes that the State of Nevada estimates are unrealistically high and that they do not represent the reasonably foreseeable consequences of severe transportation accidents.

E.2 TRANSPORTATION ANALYSIS OF THE DOMESTIC PROGRAMMATIC ALTERNATIVES

This section describes the methodologies used to assess the transportation impacts due to the transportation of nuclear materials associated with the domestic programmatic alternatives described in Chapter 2, Domestic Programmatic Alternatives. One alternative, the Thermal Reactor Recycle Fuel Cycle Alternative, Option 3, which involves recycling LWR SNF to produce fuel for high temperature gas-cooled reactors (HTGRs), has not been quantitatively analyzed because DOE does not have enough data to perform the analysis at this time. The per-shipment transportation effects of the deep burn HTGR are assumed to be similar to the HTGR discussed in Section 4.7.2, All-HTGRs (Option 2). The number of SNF shipments for the deep burn HTGR, however, would be significantly less because only 5,000 MTHM of SNF would require transport to a future geologic repository versus 55,000 MTHM discussed in Section 4.7.2, All-HTGRs (Option 2). Transportation effects of the deep burn HTGR SNF should be approximately 10 percent as much as those presented in Section 4.7.2, All-HTGRs (Option 2).

E.2.1 Routing Analysis for Domestic Programmatic Alternatives

Potential locations have not been identified for facilities that would be associated with implementation of any of the programmatic alternatives. As one input to the assessment of the impacts of material transportation relative to the programmatic alternatives, DOE calculated average fractions of rural, suburban, and urban zones adjacent to certain transportation routes, including the population densities corresponding to the three zone types. These values were calculated for the route characteristics of the transportation analysis in the *DOE Programmatic Spent Nuclear Fuel Management and INEL Environmental Restoration and Waste Management Programs Final Environmental Impact Statement*, DOE/EIS-0203, or Spent Nuclear Fuel EIS (DOE 1995e). The Spent Nuclear Fuel EIS data set was chosen due to its large size—61 reactor origin sites and 5 DOE facility destinations—and its wide geographic coverage. The five DOE sites evaluated as destinations were Hanford Site, Idaho National Laboratory, Nevada Test Site, Oak Ridge Reservation, and the Savannah River Site. The 61 origin sites provide a diverse geographical array of sites throughout the continental United States.

The routes were analyzed using the routing computer code TRAGIS (Johnson and Michelhaugh 2003), standard routing practices, and applicable routing regulations and guidelines. Route characteristics include total shipment distance between each origin and destination and the fractions of travel in rural, suburban, and urban population density zones. Population densities were determined using Census 2000 data.

The minimum value of 150 mi (241 km) was chosen as it represented the minimum shipment distance evaluated in the Spent Nuclear Fuel EIS. The maximum distance evaluated in the EIS was approximately 3,000 mi (4,828 km). The intermediate values were chosen to provide comparison of other transportation distances. Table E.2.1-1 provides a summary of the routing inputs used to analyze the transportations impacts related to the domestic programmatic alternatives.

For the Yucca Mountain FEIS (DOE 2002i), DOE entered the route distances of all the SNF shipment routes to be analyzed. The upper bound shipment was found to be 3,100 mi (5,000 km) long, and the median value was approximately 2,100 mi (3,380 km) (SNL 2005). By comparison, the average rail distance between the commercial LWR SNF origin and the Caliente destination site was 2,160 mi (3,480 km) in the Yucca Mountain SEIS transportation analysis (BMI 2007). Shipments were analyzed at the 2,100 mi (3,380 km) distance for both truck and rail transport for use as the representative case for the domestic programmatic alternatives analyses. The population density values for all five distances were updated to reflect Census 2000 data.

TABLE E.2.1-1—*Summary of Routing Inputs for Generic Domestic Programmatic Alternatives Analysis*

Route Distance (miles [km])	Distance within Population Zone (miles [km])			Population Density (/mi² [/km²])		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Legal Weight Truck Option						
150 (241)	109.6(176.4)	38.5 (62.0)	1.9 (3.1)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
500 (805)	365.3 (587.9)	128.3 (206.5)	6.4 (10.3)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
1,500 (2414)	1,096.0 (1,764.0)	385.0 (619.6)	19.0 (30.6)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
2,100 (3,380)	1,534.0 (2,469.0)	539.0 (867.4)	27.0 (43.5)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
3,000 (4,828)	2,192.0 (3,528.0)	770.0 (1,239)	38.0 (61.2)	28.7 (11.1)	838.4 (323.7)	6,143.5 (2,372.0)
Rail Option						
150 (241)	114.9 (184.9)	32.9(52.9)	2.2(3.5)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
500 (805)	383.0(616.4)	109.7 (176.5)	7.3(11.8)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
1,500 (2,414)	1,149.0(1,849.0)	329.0(529.5)	22.0(35.4)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
2,100 (3,380)	1,609.0(2,589.0)	460.6(741.2)	30.4(48.9)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)
3,000 (4,828)	2,298.0(3,698.0)	658.0(1,059.0)	44.0(70.8)	22.4 (8.65)	1,061.4 (409.8)	6,308.4 (2,435.7)

Source: Tetra Tech 2008f

Note: Due to rounding of values, the sum of the parts may not equal the total represented in the leftmost column.

Note 2: Conversion between miles and kilometers was conducted by spreadsheet software assuming one decimal point precision, which creates up to 5 significant figures, which is higher precision than other calculations in the analyses.

E.2.2 Shipment Data for Domestic Programmatic Alternatives

For this PEIS, not all fresh fuel types were analyzed for the radiological impacts of transportation accidents. Transportation accident impacts associated with MOX fuel and transmutation fuels were analyzed for this PEIS. The other fresh fuel types-LWR, thorium cycle, HWR, and HTGR-were not analyzed for accident impacts due to the unavailability of documented fresh fuel nuclide inventories. As noted in a World Nuclear Transport Institute report, the impacts of transporting fabricated uranium fuel assemblies are considered small (WNTI 2007). The fuel for the majority of nuclear reactors consists of assemblies of rods, each filled with ceramic uranium oxide pellets enriched with U-235 to less than five percent. It is assumed impacts due to incident-free shipment of fresh (unirradiated) fuel would be equivalent on a per-shipment basis for all fuel types. There would be little variance in accident impacts between the different fuel types. This assumption is based upon the transportation analysis provided in, *Environmental Impact Statement for an Early Site Permit (ESP) at the Exelon ESP Site*, hereafter NUREG 1815 (NRC 2006c). As with all enriched uranium intermediate fuel materials, the primary hazard is radiological, in the event of a criticality excursion such as an unwanted nuclear chain reaction. This type of event is prevented by the design of the package and the configuration of the packages in transport.

NUREG 1815 provides relative transportation impact estimates for fresh fuels for the different advanced LWR reactor types that correspond to reactor types considered in this PEIS. The values provided in NUREG 1815 Table G-1 reflect the expected number of truck shipments needed for each reactor for initial core loading, normal operations, and cumulative for an estimated 40-year reactor lifespan. NUREG 1815 Table G-3 provides the lifetime normalized annual radiological impacts due to transportation of fresh fuels associated with the reactor technologies. The NUREG 1815 analysis calculates impacts that are three orders of magnitude lower than those provided in 10 CFR 51.52, Table S-4. The NUREG 1815 normalized values were compared to Table S-4 to meet the conditions for an Early Site Permit described in 10 CFR 51.52(a) (10 CFR 51.52).

The NUREG 1815 analyses assumed the same per-shipment incident-free exposure risks for the transportation of fresh fuel. Cumulative annual dose risks were therefore a function of the expected number of shipments. Please note that because of the increased number of shipments attributable to low volume-to-heavy metal mass ratios, the reactor designs corresponding to the HTGR design (i.e., gas turbine modular helium reactor [GT-MHR] and the pebble bed modular reactor [PBMR]) have higher impacts than the designs associated with the other programmatic alternatives provided in this PEIS (NRC 2006c).

NUREG 1815 states that accident risks associated with transportation of fresh advanced LWR reactors would be much lower than Table S-4 conditions, making such accident analysis unnecessary to meet Early Site Permit conditions. As stated in NUREG 1815:

> *Accidents involving unirradiated fuel shipments are also addressed in Table S–4. Accident risks are the product of accident frequency times consequence. Accident frequencies are likely to be lower than those used in the analysis in WASH-1238 (AEC 1972) because traffic accident, injury, and fatality rates have fallen over the past 30 years. Consequences of accidents that are severe enough to result in a release of unirradiated fuel particles are not significantly different for advanced LWRs because the fuel form, cladding, and packaging are similar to those analyzed in WASH-1238. Consequently, the impacts of accidents during transport of unirradiated fuel to advanced LWR sites would be smaller than the WASH-1238 results that formed the basis for Table S-4.*

Considering this, it has been assumed that the accident impacts due to transportation of fresh fuels would be much lower than the accident impacts associated with the SNF types analyzed in this PEIS.

E.2.2.1 *Fresh and Spent Nuclear Fuel Shipments*

For the PEIS transportation analysis, nuclide inventories for commercial LWR SNF were based on the Advanced Fuel Cycle Facility *Conceptual Design and NEPA Support Activities NEPA Data Study* (hereafter AFCF NEPA Data Study) (WGI 2008a). The assumption was that the SNF transported would consist of fuel with a burnup of 100 gigawatt-days per metric ton uranium (GWd/MTU), with a minimum of 5 years cooling. The end-of-life effective enrichment, defined as the percentage of fissile material remaining in the heavy metal, is approximately 2.6 percent. The nuclide inventory is provided in Appendix 2 of the AFCF NEPA Data Study (WGI 2008a).

For truck transport of commercial spent nuclear fuel, the GA-4/9 cask is assumed. This cask has the capacity of four PWR assemblies. As provided in WGI 2008a, each PWR assembly is assumed to have a mass of 0.5 MTHM, so each truck cask would hold a total of 2.0 MTHM. For rail transport, the NLI-10/24 cask is assumed. This cask has a capacity of 10 PWR assemblies, or 5.0 MTHM of commercial spent nuclear fuel. Each train was assumed to be comprised of five rail cask cars so that approximately 25 MTHM SNF was transported in each rail shipment.

The AFCF NEPA Data Study provides the nuclide inventories and packaging assumptions used for the analysis of transportation of fast reactor spent fuel and fresh transmutation fuel. The fast reactor spent fuel was assumed to have a burnup of 250 GWd/MTU and a minimum cooling time of one year (WGI 2008a). Due to high activities of both the fresh and spent fuel (as well as high thermal load for the spent fuel), it was assumed that both would be transported in devalued GA 4/9 NLI-1/2 casks. It was assumed that 0.4 MTHM of the spent and fresh fuel could be transported in one assembly within the casks. The inventories for the fast reactor spent fuel and fresh transmutation fuel are provided in Appendix A-3 and Table 25 of the AFCF NEPA Data Study, respectively (WGI 2008a). The transportation of fresh transmutation fuel, and all other fresh nuclear fuels, was assumed to be conducted via truck transport only as discussed in 10 CFR 51.52.

For analysis in this PEIS, the nuclide inventory and shipping configuration of unirradiated (fresh) MOX fuel was provided by the *Environmental Impact Statement on the Construction and Operation of a Mixed Oxide Fuel Fabrication Facility at the Savannah River Site, South Carolina*, or MOX Fuel Fabrication Facility EIS (NRC 2005c). In the MOX Fuel Fabrication Facility EIS, fresh MOX fuel was assumed to be transported in a cask with a capacity of three fuel assemblies, with a heavy metal mass of approximately 1.37 MTHM (NRC 2005c). The MOX Fuel Fabrication Facility EIS did not analyze the transportation of MOX spent fuel, so the assumptions in the following paragraphs were used to assess the transportation of MOX and other programmatic spent fuels.

For shipment of fresh LWR fuel, it was assumed that the shipment configuration would be analogous with the advanced PWR (AP1000) fuel shipments analyzed in NRC 2006c. In the NRC document, it was assumed that 12 fresh fuel assemblies would be transported per shipment. Given the assumption of 0.5 MTHM per PWR assembly provided in WGI 2008a, each fresh LWR fuel shipment analyzed in the GNEP PEIS, were assumed to have 6 MTHM (12 assemblies × 0.5 MTHM/shipment = 6 MTHM).

Based on data provided in Chapter 2 of the GNEP PEIS, the initial U-235 enrichment is 12.2 percent for the thorium fuel and 19.9percent for the blanket fuel material, or 2.8-4.5 times higher than the 4.4 percent assumed for LEU LWR fuel. Assuming an average scaling factor of 3.65, compared to LWR fuel, there would be 6 MTHM/3.65 = 1.7 MTHM/shipment of fresh thorium fuel. This provides relatively the same mass of U-235 per transportation cask, and thus, the same assumed external dose rate of 0.1 mrem/hr at 1 m as provided in the analysis supporting the 10 CFR 51.52 assumptions (NRC 2006c).

NRC 2006c states that each ACR-700 (Advanced CANDU Reactor) fuel assembly contains 18 kg of uranium. This is analogous to the HWR reactor design assumed for the GNEP PEIS. Each fresh fuel shipment is assumed to hold 180 to 240 assemblies per shipment. For sake of conservativeness, the lower shipment quantity was assumed. For the HWR fresh shipments, 3.24 MTHM per shipment is assumed (18 kg U/assembly × 240 assemblies/shipment = 3240 kg U/shipment = 3.24 MTHM/shipment).

For the reactor design analogous to the HTGR design (the GT-MHR), NRC 2006c assumes the spent fuel shipments would hold 6 assemblies for a total of 0.023 MTHM. This translates to 0.00383 MTHM/assembly. NRC 2006c also states that each truck shipment of fresh fuel would be comprised of 80 assemblies. Therefore for the GNEP PEIS, it is assumed that each fresh HTGR fuel shipment would hold 0.307 MTHM of fuel (0.00383 MTHM/assembly × 80 assemblies/shipment = 0.307 MTHM/shipment).

The exact composition and physical attributes of the SNF from each programmatic alternative have not yet been determined. For the Thermal/Fast Reactor Recycle Alternative, SNF and other material characteristics were assumed to be the same as those provided in the AFCF NEPA Data Study. For the remaining programmatic alternatives, SNF from each alternative has been assigned nuclide inventories from *Source Term Estimates for DOE Spent Nuclear Fuels* (DOE 2004j). In this report, DOE SNF was organized into 34 groups based on fuel enrichment, fuel cladding material, and fuel cladding condition. The characteristics of the SNF, including percent enrichment, decay time, and burnup, affects the radionuclide inventory and, as a result, the radiation dose. A general sensitivity analysis of burnup and cooling times is provided in Chapter 4.

In determining the effects on human health from normal operations and accidents, the radionuclide inventories assumed in the transportation analyses are based on the best available data. As described in Appendices C, D, and E, these reference documents generally include previous NEPA documents, safety basis documents, and hazard analyses for similar facilities. As a result, the radionuclide inventories used to estimate impacts due to transportation accident releases may not be based on the same burnup values provided in Table 4.8-1. Given the conservative assumptions that have been made, and other variables that could affect the results presented, any differences in burnup values are considered minor.

Table E.2.2.1-1 provides the per canister nuclide concentration of the fuel groups, in curies, used to represent the SNF generated in the programmatic alternatives. These inventories were calculated for the Yucca Mountain FEIS (BMI 2007). Each fuel group provided in the source terms document (DOE 2004j) represents many different SNF types currently stored by DOE. Each fuel group has a variety of end-of-life enrichments and nuclide inventories. The fuel groups chosen best represent the reactor types and enrichment requirements associated with the domestic programmatic alternatives.

Each DOE rail cask is assumed to hold nine DOE spent fuel canisters. Therefore, each rail cask is assumed to hold the equivalent of nine truck shipments. With five rail cars per shipment, each rail shipment is assumed to transport the equivalent of 45 truck shipments of this material. It should be also noted that other spent fuel casks may be used for the transportation of the spent fuels analyzed in this PEIS. The DOE spent fuel canisters and casks were assumed due to the availability of information regarding these containers. As with most shipping configurations, transportation by rail provides for larger per-shipment capacity due to larger weight limits, which provides for greater cargo capacity, including the added weight of shielding for greater thermal and radioactivity loads.

TABLE E.2.2.1-1—*Nuclide Inventories of the Programmatic Alternative Nuclear Fuels*[a]

Nuclide	LWR SNF[b]	Fast Reactor SNF[b]	Fresh Transmutation Fuel[b]	Fresh MOX Fuel	Thorium Cycle Fuel (Group 26)	Thermal Recycle Fuel (Group 23)	HWR SNF (Group 2)	HTGR SNF (Group 19)
Ac-227	8.8×10^{-4}	2.5×10^{-7}			7.4	0.042	5.8×10^{-4}	2.6
Am-241	4.2×10^{4}	27	8.4×10^{-9}		7,100	2.5×10^{5}	2.1×10^{4}	2,300
Am-242m	220	530	8.7×10^{4}		16	2,100	34	2.2
Am-243	720	140	1,500		15	440	6.4	40
C-14	17	0.12			1.2	8,300	2,000	20
Cl-36					2.2	49	37	0.92
Cm-243	520	160	1,100		1.0	580	6.6	30
Cm-244	1.9×10^{5}	3.1×10^{4}	3.9×10^{5}		220	7,700	89	9,000
Co-60	4.4×10^{4}	50			9.5×10^{4}	3.5×10^{6}	4.6×10^{5}	2,300
Cs-134	3.0×10^{5}	1.7×10^{4}			11	4.1×10^{4}	150	3,700
Cs-135	12	0.48			2.6	49	1.9	21
Cs-137	1.4×10^{6}	2.9×10^{4}			1.4×10^{5}	2.3×10^{6}	2.2×10^{5}	1.5×10^{6}
Eu-154	9.4×10^{4}	1,600			3,200	1.1×10^{5}	1,200	3.9×10^{4}
Eu-155	2.5×10^{4}	3,500			300	6.7×10^{4}	770	5,900
Fe-55	1.1×10^{4}	6,900			3,800	4.8×10^{5}	6,200	1.6
H-3	9,000	170			550	1.7×10^{4}	4,200	6,900
I-129	0.39	0.013			0.13	1.3	0.13	0.87
Kr-85	1.0×10^{5}	5.6			5,800	8.5×10^{4}	7,500	7.9×10^{4}
Np-237	7.6	0.62			0.15	5.6	1.9	11
Pa-231	0.0012	3.3×10^{-7}			9.1	0.061	0.0011	4.1
Pb-210	3.9×10^{-5}	$1.7\ 10^{-6}$			0.0011	3.2×10^{-4}	3.6×10^{-4}	7.3×10^{-4}
Pm-147	3.2×10^{5}	3.4×10^{4}			230	2.2×10^{5}	1.6×10^{4}	5,200
Pu-238	1.0×10^{5}	1.9×10^{4}	2.2×10^{5}	430	2,900	3.8×10^{4}	3,600	1.5×10^{5}
Pu-239	2,600	370	5,600	4,900	380	1.5×10^{5}	7,100	120
Pu-240	4,000	1,400	8,400	1,100	270	1.1×10^{5}	3,500	220
Pu-241	1.1×10^{6}	1.4×10^{5}	2.3×10^{6}	4.3×10^{4}	7.1×10^{4}	4.2×10^{6}	1.4×10^{5}	3.1×10^{4}
Pu-242	38	4.6	78.4	0.096	2.2	44	1.9	3.4
Ra-226	1.1×10^{6}	5.3×10^{-6}			0.0017	4.2×10^{6}	9.7×10^{-4}	0.0012
Ra-228		2.7×10^{-12}			0.35	0.012	2.4×10^{-5}	0.78
Ru-106	1.7×10^{5}	8.2×10^{4}			0.0035	1.2×10^{4}	1,100	0.65
Se-79	1.1				2.9	13	3.1	18
Sn-126		0.40			3.2	40	2.5	19
Sr-90	1.1×10^{6}	9,600			1.4×10^{5}	1.2×10^{6}	1.6×10^{5}	1.5×10^{6}
Tc-99	180	4.0			31	480	59	290
Th-229	2.2×10^{-5}	4.3×10^{-7}			4.9	0.029	1.8×10^{-4}	5.8
Th-230	0.010	6.5×10^{-4}			0.090	0.096	0.088	0.12
Th-232		3.7×10^{-12}			0.80	0.013	2.4×10^{-5}	2.5
Tl-208					1,100	2.5	0.020	580
U-232	0.86	5.2×10^{-5}	0.039		2,900	6.7	0.054	1,600
U-233	0.0022	1.5×10^{-4}	9.9×10^{-5}		2,500	7.7	0.039	1,800
U-234	26	2.5	1.2		74	270	190	240
U-235	0.29	4.6×10^{-5}	0.013	0.0071	0.53	12	0.082	3.6
U-236	5.7	0.0025	0.26		0.22	5.1	2.8	7.4
U-238	1.4	0.0034	0.066	0.44	0.11	5.0	2.1	0.045

Source: WGI 2008a, NRC 2005c, BMI 2007

[a] All values in curies.

[b] The inventories provided are truncated to match the nuclide list following nuclide screening provided in BMI 2007. The full inventories for the LWR and fast reactor fuels are provided in WGI 2008a.

The fuel groups represented in this table are described below.

- **Group 2:** Uranium Metal, Non-Zirconium Alloy Clad, Low-Enriched Uranium. This group contains uranium metal fuel compounds with no known zirconium alloy cladding. The average end-of-life enrichment, used in this PEIS analysis, is 0.47 percent. The cladding is assumed to be in good to poor condition.
- **Group 19:** Thorium/Uranium Carbide, TRISO or BISO-Coated Particles in Graphite. This group contains thorium/uranium carbide fuel compounds with TRISO (tri-structural isotopic) or BISO (bi-structural isotopic)-coated particles. TRISO-coated particles consist of an isotropic pyrocarbon outer layer, a silicon carbide layer, an isotropic carbon layer, and a porous carbon buffer inner layer. BISO-coated particles consist of an isotropic pyrocarbon outer layer and a low density porous carbon buffer inner layer. The average end-of-life enrichment, used in this PEIS analysis, is 6.62 percent. The coating is assumed to be in good condition.
- **Group 23:** Mixed Oxide, Stainless-Steel Clad. This group contains plutonium/uranium and plutonium oxide fuel compounds with stainless steel cladding. The average end-of-life enrichment, used in this PEIS analysis, is 51.0 percent. The cladding is assumed to be in good condition.
- **Group 26:** Thorium/Uranium, Stainless-Steel Clad. This group contains thorium/uranium oxide fuel compounds with stainless-steel cladding. The average end-of-life enrichment, used in this PEIS analysis, is 3.17 percent. The cladding is assumed to be in good to fair condition.

The end-of-life enrichment values were calculated for each of the fuel groups listed above based on the U-235 mass relative to the total heavy metal mass.

The SNF from the fast recycling reactors is assumed to have a burnup of 250 GWd/MT, with a 1 year cooling period. As with the LWR SNF, the end-of-life effective enrichment is approximately 2.6 percent. The nuclide inventory is provided in Appendix A-3 of the AFCF NEPA Data Study. Nuclide inventories of other materials and wastes analyzed are provided in Section 3 of the AFCF NEPA Data Study (WGI 2008a).

E.2.2.2 *Separation Process Material and Waste Shipments*

Material and waste volumes and physical attributes, including nuclide inventory, were based on the AFCF NEPA Data Study (WGI 2008a). Packaging assumptions for the materials were based on the following source documents:

- AFCF NEPA Data Study (WGI 2008a)
- *Engineering Alternative Studies for Separations NEPA Data Input Report* (WSRC 2008a)
- AFCF Waste Volumes Estimation White Paper (WGI 2008c)

Table E.2.2.2-1 provides a summary of the containers by material type and other input parameters used in this PEIS transportation analysis. These values are based on the AFCF NEPA Data Study and *Estimation of AFCF HLW and GTCC Waste Volumes to Support the GNEP PEIS (*hereafter the AFCF Waste Volumes Estimation White Paper) (WGI 2008a, WGI 2008c).

Volumes per container type also are provided in the table as well as the limiting factor used to determine the bulk container volumes. The transportation analysis was conducted using a conservative package type for transuranic wastes due to unknowns of specific waste acceptance criteria for a future receiving disposal location and limited process design detail that identifies the percentage of waste which could require a less rigorous package. It should be noted that there are some volume differences in HLW canister volume largely due to differences in void space between the various waste forms.

For the shipment of greater-than-Class-C (GTCC) LLW, this analysis assumes transport in a HLW canister with a volume of 28.1 ft^3 (0.795 m^3) per canister. An alternative package for shipping remote handled transuranic waste by DOE is a RH-72B cask, which has a volume of 22 ft^3 (0.624 m^3) per cask. Both of these options are limited to a single canister/cask per shipment. If the transuranic waste is determined to be contact handled waste, a container such as a standard waste box could be used for shipment. The standard waste box has a capacity of 67 ft^3 (1.9 m^3 or four 55-gallon drums) per box and when loaded into a DOE TRUPACT II shipping container, has a potential for six standard waste boxes per shipment. The use of standard waste boxes in shipping contact handled transuranics would greatly reduce the number of shipments needed. The actual number of shipments needed would be determined based on the specific waste types and DOT regulations. If contact handled waste is transported in a waste package, such as the standard waste box rather than the HLW canister, the number of shipments could be reduced by a factor of approximately 13, which would also result in a reduction of the associated transportation impacts by the same factor.

TABLE E.2.2.2-1—*Transportation Containers for Analyzed Shipments by Material Type*

Material to be Transported	Name of Canister or Cask	Volume or Mass per Container	Number of Containers per Shipment Truck (Rail)	Limiting Factor	External Exposure (mrem/hr at 2 m)
LWR SNF	GA-4/9 or NLI–10/24	truck 2—MTHM rail—5 MTHM	1 (5)	Volume and thermal	10
Fresh LWR fuel [a]	--	6 MTHM	1	Volume and criticality	0.0521
SNF from MOX, thorium, HWR, and HTGR cycles	DOE SNF cask	truck—1 assembly rail—9 assemblies	1 (5)	Volume and Thermal	10
Fresh MOX fuel [a,b]	Class B cylindrical container	3 assemblies	1	Volume and criticality	2.52
Fresh transmutation fuel	NLI-1/2	0.4 MTHM	1	Thermal and Criticality	10
Fresh thorium fuels [a]	--	1.7 MTHM	1	Volume and criticality	0.0521
Fresh HWR fuel [a]	--	3.24 MTHM	1	Volume and criticality	0.0521
Fresh HTGR fuel [a]	--	0.307	1	Volume and criticality	0.0521
Recovered uranium (oxide)	Class B 9975 drums	13.5 kg total U	15 (75)	Criticality	5
Recovered uranium (metal)	Class B 9975 drums	17.2 kg	18 (90)	Criticality	5
Fast reactor SNF	NLI-1/2 [c]	1 assembly	1 (5)	Thermal	10
Technetium, un-dissolved solids (UDS), and fuel cladding hulls in metal waste form [d, e]	HLW canister [f]	0.77 m^3	1 (5)	Volume	10
Lanthanides and other fission product waste [d]	HLW canister [f]	1.29 m^3	1 (5)	Volume	10
Cesium/strontium in hydroceramic waste form	Waste cans (3” IDx10’ long)	0.067 m^3	1 (5)	Thermal	10
GTCC LLW including absorbed/stabilized volatile fission products, spent equipment, and compacted HEPA filters.	HLW canister [f]	0.79 m^3	1 (5)	Volume	10
Low-level radioactive waste and mixed low-level radioactive waste.	B-25 Box	2.55 m^3	12 (60)	Volume	2

Source: WGI 2008a, WGI 2008c

[a] Transportation of fresh nuclear fuel is assumed to be via truck transport only. No specific transportation casks have yet been identified for the LWR, thorium, HWR , and HTGR fresh fuels transportation.

[b] Source NRC 2005c.

[c] Currently the NLI-1/2 is only certified for truck shipments. It is assumed that this cask or a similar model will be certified for rail transportation by the operational timeframe of this program.

[d] The HLW described in Chapter 4 is represented by two different waste streams; the Tc/UDS/hulls and Ln/fission product wastes. Tc/UDS/hulls wastes comprise approximately 45 percent of the total HLW by volume, and Ln/FP wastes comprise 55 percent.

[e] The metal hulls in this waste stream are assumed to be melted with the technetium and undissolved solids to act as a binding material.

[f] For the purposes of this analysis, some waste streams were assumed to be packaged in HLW canisters that would not be classified as HLW. Waste classification and selection of specific transportation casks would be completed as the facility design and waste characteristics are further developed.

Table E.2.2.2-2 provides the estimated number of truck shipments over approximately a 50-year period associated with achieving a nuclear electricity capacity of 200 GWe in approximately 2060-2070, based on a 1.3 percent annual growth rate. The PEIS assumes that new LWR capacity would begin to come on-line in approximately 2015 and that the programmatic action alternatives would be implemented over this timeframe.

Table E.2.2.2-3 provides the number of rail shipments needed to meet the same 200 GWe capacity over the same timeframe. The numbers of shipments provided in the table were calculated based on the source documents listed in Section E.2.2.2. These values were calculated on the basis of all shipments containing the same mass and volumes provided in the source documents. If the fast reactors and the recycling facility are colocated, the inter-site transportation of fresh fast reactor fuel and spent fast reactor fuel would be eliminated. This would result in substantial decreases in the transportation impacts.

The transportation impact values provided in Chapter 4 represent total exposure impacts over the entire affected population during the program period. It should not be assumed that affected populations, including workers, driving crews, and on-link traffic, receive multiple exposures. The exposure values, calculated in person-rem, represent a collective dose to the population within 0.5 mi (800 m) of the transportation routes analyzed. To provide comparison of impacts between the different alternatives, the cumulative exposure numbers were multiplied by the 6×10^{-4} dose conversion factor (DOE 2002h) to provide an estimate of LCFs due to the transportation of the radioactive materials.

A more complete description of the amount of SNF processed and the basis for materials generated by each domestic programmatic alternative are provided in Chapter 4. The mass or volume values provided were then used to calculate the necessary number of containers based on the NEPA source documents provided at the introduction to this section.

TABLE E.2.2.2-2—*Number of Shipments per Material Type—All-Truck Scenario—200 Gigawatts Electric*

Material/Waste Type	No Action Alternative	All-Fast Recycle	Thermal/ Fast	Thermal Option 1	Thermal Option 2	Thorium Cycle	All-HWR	All-HTGR
LWR SNF	7.90×10^4	5.90×10^4	6.30×10^4	1.10×10^4	7.05×10^4	5.05×10^4	3.40×10^4	3.40×10^4
Fast reactor SNF		3.50×10^4	2.75×10^4					
Cs/Sr waste		1.08×10^4	1.08×10^4	1.08×10^4				
Ln/fission product waste [a]		2.25×10^4	2.21×10^4	2.13×10^4	1.30×10^4			
Tc/UDS/hulls waste		3.11×10^4	3.06×10^4	2.94×10^4	1.80×10^4			
GTCC LLW AND MLLW	3,200	5.24×10^5	5.04×10^5	5.13×10^5	1.00×10^4	3,200	3,200	3,200
LLW AND MLLW	1.90×10^4	9.34×10^4	8.32×10^4	8.40×10^4	2.30×10^4	1.90×10^4	1.90×10^4	1.90×10^4
Recovered uranium (oxide)		1.64×10^4	1.83×10^4	2,920	1.90×10^4			
Recovered uranium (metal)		7,580	5,960					
MOX SNF [b]			8,000	1.95×10^5				
Thorium SNF						1.55×10^5		
HWR SNF					4.48×10^4		1.14×10^5	
HTGR SNF								1.56×10^6
Fresh LWR fuel	2.63×10^4	1.97×10^4	2.10×10^4	3,670	2.35×10^4	1.68×10^4	1.13×10^4	1.13×10^4
Fresh transmutation fuel		3.50×10^4	2.75×10^4					
Fresh MOX fuel [c]			4,380	1.07×10^5				
Fresh thorium fuel						2.28×10^4		
Fresh HWR fuel					2.19×10^4		5.56×10^4	
Fresh HTGR fuel								1.05×10^5

Source: Tetra Tech 2008f

[a] These two sources are combined in Chapter 4 analysis to represent high-level waste, or HLW.

[b] For this PEIS, HTGR SNF was assumed to be disposed in the form of whole fuel elements. This process has the disadvantage of requiring considerably more volume of storage of a unit weight of fuel and fission product isotopes. A typical DOE canister is sized to contain spent nuclear fuel assemblies equivalent to a spent nuclear fuel quantity of about 1 MTHM. By comparison, an equivalent waste canister would contain a vertical stack of four fuel blocks (Fort St. Vrain type), or approximately 40 kg of heavy metal, requiring many more shipments of SNF when compared to other fuel cycle options (Shropshire and Herring 2004).

[c] The MOX spent fuel was assumed to be transported in DOE spent fuel canisters, with a capacity of 0.75 MTHM per container. Fresh MOX fuel was assumed to be transported in Class B containers as described in NRC 2005c. These containers have a capacity of 1.37 MTHM per shipment and are not appropriate for the shipment of spent fuel. Considering this, there would be approximately 83 percent more spent fuel shipments than fresh for the same amount of fuel. Shipment of the other fresh fuels assumed the same container as their spent fuel counterpart, with the same capacities.

TABLE E.2.2.2-3—*Number of Shipments per Material Type—All-Rail Scenario—200 Gigawatts Electric*

Material/Waste Type	No Action	All-Fast Recycle	Thermal/ Fast	Thermal Option 1	Thermal Option 2	Thorium Cycle	All-HWR	All-HTGR
LWR SNF	6,320	4,720	5,280	880	5,640	4,040	2,720	2,720
Fast reactor SNF		7,000	5,500					
Cs/Sr waste (aqueous process)		2,150	2,150	2,150				
Ln/fission product waste [a]		4,500	4,420	4,240	2,600			
Tc/UDS/hulls waste [a]		6,200	6,120	5,860	3,600			
GTCC LLW AND MLLW	630	1.03×10^5	1.01×10^5	1.01×10^5	2,000	630	630	630
LLW AND MLLW	3,800	1.89×10^4	1.66×10^4	1.70×10^4	4,500	3,800	3,800	3,800
Recovered uranium (oxide)		3,200	3,660	584	3,800			
Recovered uranium (metal)		1,520	1,190					
MOX SNF			178	4,330				
Thorium SNF						3,450		
HWR SNF					996		2,500	
HTGR SNF								3.30×10^4
Truck shipments of fresh fuel								
Fresh LWR fuel [b]	2.63×10^4	1.97×10^4	2.10×10^4	3,670	2.35×10^4	1.68×10^4	1.13×10^4	1.13×10^4
Fresh transmutation fuel [b]		3.50×10^4	2.75×10^4					
Fresh MOX fuel [b]			4,380	1.07×10^5				
Fresh thorium fuel [b]						2.28×10^4		
Fresh HWR fuel [b]					2.19×10^4		5.56×10^4	
Fresh HTGR fuel [b]								1.05×10^5

Source: Tetra Tech 2008f

[a] These two sources are combined in Chapter 4 analysis to represent high-level waste, or HLW

[b] All shipment of fresh nuclear fuel is assumed be to via truck transport.

E.2.3 Loading Operations—Domestic Programmatic Alternatives

Loading operations typically represent the largest exposure impacts involved with the transportation of nuclear materials. As in the Yucca Mountain FEIS and SEIS (DOE 2002i, DOE 2008f), DOE assumed that exposure due to loading operations would total approximately 0.432 person-rem and 0.663 person-rem for truck and rail SNF casks respectively. The values provided in the Yucca Mountain documents are based on actual exposure values provided in industry documents detailing loading operations of commercial SNF.

Estimation of loading operation impacts of other materials and waste products was based on the size and number of packages per load. Table E.2.3-1 provides the input parameters for estimation of impacts of loading operations for non-SNF domestic programmatic materials. These parameters, along with the exposure rates provided in Table 2.2.2-1, were used to calculate the range of exposure rates provided in subsequent sections and tables.

TABLE E.2.3-1—*Per-Shipment Loading Parameters for Domestic Programmatic Alternatives*

Material Type	Number of Handlers	Loading Time (hr)
Legal-Weight Truck Scenario		
Spent fuels [a]	13	10
Am oxide product	5	12
Cm oxide product	5	12
Consolidated TRU/U product	5	12
Spent fuels [a]	13	10
Cs/Sr waste	5	8
Ln/fission product waste	5	4
Tc/UDS/hulls waste	5	4
GTCC LLW AND MLLW	5	4
LLW and MLLW	5	12
Recovered uranium (oxide)	5	12
Recovered uranium (metal)	5	8
Mostly-Rail Scenario [c]		
Spent fuels	13	90
Am oxide product	5	60
Cm oxide product	5	60
Cs/Sr waste	5	40
Ln/Fission Product waste	5	20
Tc/UDS/hulls waste	5	20
GTCC LLW AND MLLW	5	20
LLW and MLLW	5	60
Recovered uranium (oxide)	5	60
Recovered uranium (metal)	5	40

Source: Tetra Tech 2008f

[a] The loading impacts are equal to the loading impacts provided in the Yucca Mountain SEIS (DOE 2008f). The loading operations in the Yucca Mountain SEIS assume a crew of 13 workers conducting multiple tasks at various distances to the source and for various times.

[b] Loading of fresh fuel shipments assumed to have the same labor and time requirements as spent fuel shipments.

[c] Fresh fuels shipments were assumed to be conducted by truck only, including in the rail scenario. These shipments represent the only truck shipments included in the mostly rail scenario.

E.2.4 Incident-Free Transportation Impacts—Domestic Programmatic Alternatives

Incident-free impacts associated with the domestic programmatic alternatives were conducted on a per-shipment basis with the input parameters discussed in Section E.1.4 above. The per-shipment risk results are provided in Tables E.2.4-1 through E.2.4-8. The crew impacts provided in these tables are for the truck drivers or the rail crew present on the shipments. Exposure impacts to escorts are provided in Tables E.2.4-9 and E.2.4-10.

TABLE E.2.4-1—*Per-Shipment Radiological Exposure Handling Impacts and Impacts at Stops—Domestic Programmatic Alternative Scenarios—Spent Nuclear Fuel—All-Truck Option*

Mileage	Handling Impacts				Impacts at Stops			
	Loading [a]		Inspection		Truck Stop		Nearby Residents	
	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
150	0.432	3×10^{-4}	0.0738	4×10^{-5}	3.06×10^{-7}	2×10^{-10}	4.63×10^{-6}	3×10^{-9}
500	0.432	3×10^{-4}	0.0738	4×10^{-5}	1.02×10^{-6}	6×10^{-10}	1.55×10^{-5}	9×10^{-9}
1,500	0.432	3×10^{-4}	0.0738	4×10^{-5}	3.06×10^{-6}	2×10^{-9}	4.63×10^{-5}	3×10^{-8}
2,100	0.432	3×10^{-4}	0.0738	4×10^{-5}	4.29×10^{-6}	3×10^{-9}	6.48×10^{-5}	4×10^{-8}
3,000	0.432	3×10^{-4}	0.0738	4×10^{-5}	6.13×10^{-6}	4×10^{-9}	9.26×10^{-5}	6×10^{-8}

[a] Loading impacts based on Yucca Mountain FEIS and SEIS (DOE 2002i, DOE 2008f)

TABLE E.2.4-2—*Per-Shipment In-Transit Incident-Free Impacts—Domestic Programmatic Alternative Scenarios—Spent Nuclear Fuel —All-Truck Option*

Mileage	Crew Impacts		Impacts to Public		Nonradiological Emission Fatalities
	Person-Rem	LCFs	Person-Rem	LCFs	
150	0.0121	7×10^{-6}	0.0609	4×10^{-5}	3.62×10^{-9}
500	0.0405	2×10^{-5}	0.203	1×10^{-4}	1.21×10^{-8}
1,500	0.121	7×10^{-5}	0.608	4×10^{-4}	3.62×10^{-8}
2,100	0.169	1×10^{-4}	0.851	5×10^{-4}	5.07×10^{-8}
3,000	0.243	2×10^{-4}	1.22	7×10^{-4}	7.24×10^{-8}

Source: Tetra Tech 2008f

TABLE E.2.4-3—*Per-Shipment Loading Impacts Associated with Thermal/Fast Reactor Recycle Alternative—All-Truck Option*

	Mileage	Handling Impacts				Impacts at Stops			
		Loading		Inspection		Truck Stop		Nearby Residents	
		Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
Fresh transmutation fuel	150	0.432	3×10^{-4}	0.0738	4×10^{-5}	3.06×10^{-7}	2×10^{-10}	4.63×10^{-6}	3×10^{-9}
	500	0.432	3×10^{-4}	0.0738	4×10^{-5}	1.02×10^{-6}	6×10^{-10}	1.55×10^{-5}	9×10^{-9}
	1,500	0.432	3×10^{-4}	0.0738	4×10^{-5}	3.06×10^{-6}	2×10^{-9}	4.63×10^{-5}	3×10^{-8}
	2,100	0.432	3×10^{-4}	0.0738	4×10^{-5}	4.28×10^{-6}	3×10^{-9}	6.48×10^{-5}	4×10^{-8}
	3,000	0.432	3×10^{-4}	0.0738	4×10^{-5}	6.13×10^{-6}	4×10^{-9}	9.25×10^{-5}	6×10^{-8}
Fresh MOX fuel	150	0.109	7×10^{-5}	0.0186	1×10^{-5}	7.71×10^{-8}	5×10^{-11}	1.77×10^{-6}	7×10^{-10}
	500	0.109	7×10^{-5}	0.0186	1×10^{-5}	2.57×10^{-7}	2×10^{-10}	3.91×10^{-6}	2×10^{-9}
	1,500	0.109	7×10^{-5}	0.0186	1×10^{-5}	7.71×10^{-7}	5×10^{-10}	1.77×10^{-5}	7×10^{-9}
	2,100	0.109	7×10^{-5}	0.0186	1×10^{-5}	1.08×10^{-6}	6×10^{-10}	1.63×10^{-5}	1×10^{-8}
	3,000	0.109	7×10^{-5}	0.0186	1×10^{-5}	1.54×10^{-6}	9×10^{-10}	2.33×10^{-5}	1×10^{-8}
Fresh LWR, thorium, HWR, HTGR fuels	150	0.0225	1×10^{-5}	0.00384	2×10^{-6}	1.59×10^{-8}	1×10^{-11}	2.41×10^{-7}	1×10^{-10}
	500	0.0225	1×10^{-5}	0.00384	2×10^{-6}	5.31×10^{-8}	3×10^{-11}	8.08×10^{-7}	5×10^{-10}
	1,500	0.0225	1×10^{-5}	0.00384	2×10^{-6}	1.59×10^{-7}	1×10^{-10}	2.41×10^{-6}	1×10^{-9}
	2,100	0.0225	1×10^{-5}	0.00384	2×10^{-6}	2.23×10^{-7}	1×10^{-10}	3.38×10^{-6}	2×10^{-9}
	3,000	0.0225	1×10^{-5}	0.00384	2×10^{-6}	3.19×10^{-7}	2×10^{-10}	4.82×10^{-6}	3×10^{-9}
Am oxide product	150	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.154	9×10^{-5}	0.0641	4×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.154	9×10^{-5}	0.0641	4×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}
Cm oxide product	150	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.154	9×10^{-5}	0.0641	4×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.154	9×10^{-5}	0.0641	4×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}

TABLE E.2.4-3—*Per-Shipment Loading Impacts Associated with Thermal/Fast Reactor Recycle Alternative—All-Truck Option (continued)*

	Mileage	Handling Impacts				Impacts at Stops			
		Loading		Inspection		Truck Stop		Nearby Residents	
		Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
Pu/Np oxide product	150	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.154	9×10^{-5}	0.0641	4×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.154	9×10^{-5}	0.0641	4×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}
Consolidated TRU/U product	150	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.154	9×10^{-5}	0.0641	4×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.154	9×10^{-5}	0.0641	4×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}
Cs/Sr waste	150	0.821	5×10^{-4}	0.0205	1×10^{-5}	2.98×10^{-7}	2×10^{-10}	4.02×10^{-6}	2×10^{-9}
	500	0.821	5×10^{-4}	0.0205	1×10^{-5}	9.97×10^{-7}	6×10^{-10}	1.34×10^{-5}	8×10^{-9}
	1,500	0.821	5×10^{-4}	0.0205	1×10^{-5}	2.98×10^{-6}	2×10^{-9}	4.02×10^{-5}	2×10^{-8}
	2,100	0.821	5×10^{-4}	0.0205	1×10^{-5}	4.17×10^{-6}	3×10^{-9}	5.63×10^{-5}	3×10^{-8}
	3,000	0.821	5×10^{-4}	0.0205	1×10^{-5}	5.97×10^{-6}	4×10^{-9}	8.04×10^{-5}	5×10^{-8}
Ln/fission product waste	150	0.326	2×10^{-4}	0.0163	1×10^{-5}	3.00×10^{-7}	2×10^{-10}	4.17×10^{-6}	2×10^{-9}
	500	0.326	2×10^{-4}	0.0163	1×10^{-5}	1.00×10^{-6}	6×10^{-10}	1.39×10^{-5}	8×10^{-9}
	1,500	0.326	2×10^{-4}	0.0163	1×10^{-5}	3.00×10^{-6}	2×10^{-9}	4.17×10^{-5}	2×10^{-8}
	2,100	0.326	2×10^{-4}	0.0163	1×10^{-5}	4.21×10^{-6}	3×10^{-9}	5.84×10^{-5}	3×10^{-8}
	3,000	0.326	2×10^{-4}	0.0163	1×10^{-5}	6.01×10^{-6}	4×10^{-9}	8.34×10^{-5}	5×10^{-8}
Tc/UDS/hulls waste	150	0.325	2×10^{-4}	0.0162	1×10^{-5}	2.98×10^{-7}	2×10^{-10}	4.02×10^{-6}	2×10^{-9}
	500	0.325	2×10^{-4}	0.0162	1×10^{-5}	9.97×10^{-7}	6×10^{-10}	1.34×10^{-5}	8×10^{-9}
	1,500	0.325	2×10^{-4}	0.0162	1×10^{-5}	2.98×10^{-6}	2×10^{-9}	4.02×10^{-5}	2×10^{-8}
	2,100	0.325	2×10^{-4}	0.0162	1×10^{-5}	4.12×10^{-6}	3×10^{-9}	5.63×10^{-5}	3×10^{-8}
	3,000	0.325	2×10^{-4}	0.0162	1×10^{-5}	5.96×10^{-6}	4×10^{-9}	8.04×10^{-5}	5×10^{-8}

TABLE E.2.4-3—*Per-Shipment Loading Impacts Associated with Thermal/Fast Reactor Recycle Alternative—All-Truck Option (continued)*

	Mileage	Handling Impacts				Impacts at Stops			
		Loading		Inspection		Truck Stop		Nearby Residents	
		Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
GTCC LLW AND MLLW	150	0.125	8×10^{-5}	0.00625	4×10^{-6}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.125	8×10^{-5}	0.00625	4×10^{-6}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.125	8×10^{-5}	0.00625	4×10^{-6}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.125	8×10^{-5}	0.00625	4×10^{-6}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.125	8×10^{-5}	0.00625	4×10^{-6}	2.58×10^{-7}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}
LLW and MLLW	150	0.0212	1×10^{-5}	0.00210	1×10^{-6}	5.16×10^{-8}	3×10^{-11}	6.95×10^{-7}	4×10^{-10}
	500	0.0212	1×10^{-5}	0.00210	1×10^{-6}	1.73×10^{-7}	1×10^{-10}	2.32×10^{-6}	1×10^{-9}
	1,500	0.0212	1×10^{-5}	0.00210	1×10^{-6}	5.16×10^{-7}	3×10^{-10}	6.59×10^{-6}	4×10^{-9}
	2,100	0.0212	1×10^{-5}	0.00210	1×10^{-6}	7.23×10^{-7}	4×10^{-10}	9.23×10^{-6}	6×10^{-9}
	3,000	0.0212	1×10^{-5}	0.00210	1×10^{-6}	1.03×10^{-6}	6×10^{-10}	1.39×10^{-5}	8×10^{-9}
Recovered uranium (oxide)	150	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.154	9×10^{-5}	0.0641	4×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.154	9×10^{-5}	0.0641	4×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.154	9×10^{-5}	0.0641	4×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}
Recovered uranium (metal)	150	0.103	6×10^{-5}	0.0461	3×10^{-5}	1.29×10^{-7}	8×10^{-11}	1.74×10^{-6}	1×10^{-9}
	500	0.103	6×10^{-5}	0.0461	3×10^{-5}	4.31×10^{-7}	3×10^{-10}	5.81×10^{-6}	3×10^{-9}
	1,500	0.103	6×10^{-5}	0.0461	3×10^{-5}	1.29×10^{-6}	8×10^{-10}	1.74×10^{-5}	1×10^{-8}
	2,100	0.103	6×10^{-5}	0.0461	3×10^{-5}	1.81×10^{-6}	1×10^{-9}	2.44×10^{-5}	1×10^{-8}
	3,000	0.103	6×10^{-5}	0.0461	3×10^{-5}	2.58×10^{-6}	2×10^{-9}	3.48×10^{-5}	2×10^{-8}

Source: Tetra Tech 2008f

TABLE E.2.4-4—*Per-Shipment Incident-Free In-Transit Impacts—Thermal/Fast Reactor Recycle Alternative—All-Truck Option*

	Mileage	Crew Impacts		Impacts to Public		Nonradiological Emission Fatalities
		Person-Rem	LCFs	Person-Rem	LCFs	
Fresh transmutation fuel	150	0.0121	7×10^{-6}	0.0609	4×10^{-5}	3.62×10^{-9}
	500	0.0405	2×10^{-5}	0.203	1×10^{-4}	1.21×10^{-8}
	1,500	0.121	7×10^{-5}	0.608	4×10^{-4}	3.62×10^{-8}
	2,100	0.169	1×10^{-4}	0.851	5×10^{-4}	5.07×10^{-8}
	3,000	0.243	2×10^{-4}	1.22	7×10^{-4}	7.24×10^{-8}
Fresh MOX fuel	150	5.69×10^{-4}	3×10^{-7}	0.0134	8×10^{-6}	3.62×10^{-9}
	500	0.00190	1×10^{-6}	0.0511	3×10^{-5}	1.21×10^{-8}
	1,500	0.00569	3×10^{-6}	0.134	8×10^{-5}	3.62×10^{-8}
	2,100	0.00796	5×10^{-6}	0.188	1×10^{-4}	5.07×10^{-8}
	3,000	0.0143	9×10^{-6}	0.268	2×10^{-4}	7.24×10^{-8}
Fresh LWR, thorium, HWR, and HTGR fuel	150	9.90×10^{-5}	6×10^{-8}	4.98×10^{-5}	3×10^{-8}	3.62×10^{-9}
	500	3.31×10^{-4}	2×10^{-7}	1.68×10^{-4}	1×10^{-7}	1.21×10^{-8}
	1,500	9.90×10^{-4}	6×10^{-7}	4.97×10^{-4}	3×10^{-7}	3.62×10^{-8}
	2,100	0.00138	8×10^{-7}	6.96×10^{-4}	4×10^{-7}	5.07×10^{-8}
	3,000	0.00198	1×10^{-6}	9.94×10^{-4}	6×10^{-7}	7.24×10^{-8}
Am oxide product	150	0.00903	5×10^{-6}	0.0264	2×10^{-5}	3.62×10^{-9}
	500	0.0301	2×10^{-5}	0.0880	5×10^{-5}	1.21×10^{-8}
	1,500	0.0902	5×10^{-5}	0.264	2×10^{-4}	3.62×10^{-8}
	2,100	0.126	8×10^{-5}	0.370	2×10^{-4}	5.07×10^{-8}
	3,000	0.180	1×10^{-4}	0.527	3×10^{-4}	7.24×10^{-8}
Cm oxide product	150	0.00903	5×10^{-6}	0.0250	2×10^{-5}	3.62×10^{-9}
	500	0.0301	2×10^{-5}	0.0830	5×10^{-5}	1.21×10^{-8}
	1,500	0.0902	5×10^{-5}	0.249	1×10^{-4}	3.62×10^{-8}
	2,100	0.126	8×10^{-5}	0.349	2×10^{-4}	5.07×10^{-8}
	3,000	0.180	1×10^{-4}	0.497	3×10^{-4}	7.24×10^{-8}
Consolidated TRU/U product	150	0.00903	5×10^{-6}	0.0249	1×10^{-5}	3.62×10^{-9}
	500	0.0301	2×10^{-5}	0.0830	5×10^{-5}	1.21×10^{-8}
	1,500	0.0902	5×10^{-5}	0.249	1×10^{-4}	3.62×10^{-8}
	2,100	0.126	8×10^{-5}	0.349	2×10^{-4}	5.07×10^{-8}
	3,000	0.180	1×10^{-4}	0.497	3×10^{-4}	7.24×10^{-8}
Cs/Sr waste	150	0.0112	7×10^{-6}	0.0588	4×10^{-5}	3.62×10^{-9}
	500	0.0373	2×10^{-5}	0.196	1×10^{-4}	1.21×10^{-8}
	1,500	0.112	7×10^{-5}	0.587	3×10^{-4}	3.62×10^{-8}
	2,100	0.153	9×10^{-5}	0.822	5×10^{-4}	5.07×10^{-8}
	3,000	0.224	1×10^{-4}	1.17	7×10^{-4}	7.24×10^{-8}
Ln/fission product waste	150	0.00398	2×10^{-6}	0.0593	4×10^{-5}	3.62×10^{-9}
	500	0.0103	6×10^{-6}	0.197	1×10^{-4}	1.21×10^{-8}
	1,500	0.0308	2×10^{-5}	0.593	4×10^{-4}	3.62×10^{-8}
	2,100	0.0420	3×10^{-5}	0.808	5×10^{-4}	5.07×10^{-8}
	3,000	0.0615	4×10^{-5}	1.19	7×10^{-4}	7.24×10^{-8}
Tc/UDS/hulls waste	150	0.0151	9×10^{-6}	0.0588	4×10^{-5}	3.62×10^{-9}
	500	0.0504	3×10^{-5}	0.196	1×10^{-4}	1.21×10^{-8}
	1,500	0.151	9×10^{-5}	0.587	4×10^{-4}	3.62×10^{-8}
	2,100	0.211	1×10^{-4}	0.822	5×10^{-4}	5.07×10^{-8}
	3,000	0.303	2×10^{-4}	1.17	7×10^{-4}	7.24×10^{-8}

TABLE E.2.4-4—*Per-Shipment Incident-Free In-Transit Impacts—Thermal/Fast Reactor Recycle Alternative—All-Truck Option (continued)*

	Mileage	Crew Impacts		Impacts to Public		Nonradiological Emission Fatalities
		Person-Rem	LCFs	Person-Rem	LCFs	
GTCC LLW AND MLLW	150	0.0151	9×10^{-6}	0.0254	2×10^{-5}	3.62×10^{-9}
	500	0.0504	3×10^{-5}	0.0846	5×10^{-5}	1.21×10^{-8}
	1,500	0.151	9×10^{-5}	0.254	2×10^{-4}	3.62×10^{-8}
	2,100	0.211	1×10^{-4}	0.356	2×10^{-4}	5.07×10^{-8}
	3,000	0.303	2×10^{-4}	0.507	3×10^{-4}	7.24×10^{-8}
LLW AND MLLW	150	0.00320	2×10^{-6}	0.0102	6×10^{-6}	3.62×10^{-9}
	500	0.0107	6×10^{-6}	0.0339	2×10^{-5}	1.21×10^{-8}
	1,500	0.0320	2×10^{-5}	0.102	6×10^{-5}	3.62×10^{-8}
	2,100	0.0448	2×10^{-5}	0.143	8×10^{-5}	5.07×10^{-8}
	3,000	0.0640	4×10^{-5}	0.203	1×10^{-4}	7.24×10^{-8}
Recovered uranium (oxide)	150	0.0147	9×10^{-6}	0.0249	1×10^{-5}	3.62×10^{-9}
	500	0.0504	3×10^{-5}	0.0846	5×10^{-5}	1.21×10^{-8}
	1,500	0.147	9×10^{-5}	0.249	1×10^{-4}	3.62×10^{-8}
	2,100	0.206	1×10^{-4}	0.347	2×10^{-4}	5.07×10^{-8}
	3,000	0.294	2×10^{-4}	0.496	3×10^{-4}	7.24×10^{-8}
Recovered uranium (metal)	150	0.0147	9×10^{-6}	0.0249	1×10^{-5}	3.62×10^{-9}
	500	0.0504	3×10^{-5}	0.0846	5×10^{-5}	1.21×10^{-8}
	1,500	0.147	9×10^{-5}	0.249	1×10^{-4}	3.62×10^{-8}
	2,100	0.206	1×10^{-4}	0.347	2×10^{-4}	5.07×10^{-8}
	3,000	0.294	2×10^{-4}	0.496	3×10^{-4}	7.24×10^{-8}

Source: Tetra Tech 2008f

TABLE E.2.4-5—*Per-Shipment Radiological Exposure Handling Impacts and Impacts at Stops—Domestic Programmatic Alternative Scenarios—Spent Nuclear Fuel—All-Rail Option*

Mileage	Handling Impacts				Impacts at Stops			
	Loading[a]		Inspection		Railyard Workers		Nearby Residents	
	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
150	3.32	0.002	0.185	1×10^{-4}	1.27×10^{-6}	8×10^{-10}	2.38×10^{-4}	1×10^{-7}
500	3.32	0.002	0.185	1×10^{-4}	4.22×10^{-6}	3×10^{-9}	7.95×10^{-4}	5×10^{-7}
1,500	3.32	0.002	0.185	1×10^{-4}	1.27×10^{-5}	8×10^{-9}	0.00238	1×10^{-6}
2,100	3.32	0.002	0.185	1×10^{-4}	1.78×10^{-5}	1×10^{-8}	0.00333	2×10^{-6}
3,000	3.32	0.002	0.185	1×10^{-4}	2.53×10^{-5}	2×10^{-8}	0.00476	3×10^{-6}

Source: Tetra Tech 2008f

[a] Loading exposure values from Yucca Mountain FEIS (DOE 2002i)

TABLE E.2.4-6—*Per-Shipment Incident-Free In-Transit Impacts—Domestic Programmatic Alternative Scenarios—Spent Nuclear Fuel [a]—All-Rail Option*

Mileage	Crew Impacts		Impacts to Public		Nonradiological Emission Fatalities
	Person-Rem	LCFs	Person-Rem	LCFs	
150	0.111	7×10^{-5}	0.0126	8×10^{-6}	6.28×10^{-9}
500	0.158	1×10^{-4}	0.0421	3×10^{-5}	2.09×10^{-8}
1,500	0.292	2×10^{-4}	0.126	8×10^{-5}	6.28×10^{-8}
2,100	0.367	2×10^{-4}	0.150	9×10^{-5}	8.78×10^{-8}
3,000	0.493	3×10^{-4}	0.253	2×10^{-4}	1.26×10^{-7}

Source: Tetra Tech 2008f

TABLE E.2.4-7—*Per-Shipment Loading Impacts Associated with Thermal/Fast Reactor Recycle Alternative—All-Rail Option*

	Mileage	Handling Impacts				Impacts at Stops			
		Loading		Inspection		Rail Yard		Nearby Residents	
		Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
Cs/Sr waste	150	4.11	0.002	0.103	6×10^{-5}	5.31×10^{-5}	3×10^{-8}	3.29×10^{-6}	2×10^{-9}
	500	4.11	0.002	0.103	6×10^{-5}	1.77×10^{-4}	1×10^{-7}	1.10×10^{-5}	7×10^{-9}
	1,500	4.11	0.002	0.103	6×10^{-5}	5.31×10^{-4}	3×10^{-7}	3.29×10^{-5}	2×10^{-8}
	2,100	4.11	0.002	0.103	6×10^{-5}	7.43×10^{-4}	4×10^{-7}	4.61×10^{-5}	3×10^{-8}
	3,000	4.11	0.002	0.103	6×10^{-5}	0.00106	6×10^{-7}	6.58×10^{-5}	4×10^{-8}
Ln/fission product waste	150	1.45	0.003	0.145	9×10^{-5}	4.42×10^{-5}	3×10^{-8}	3.29×10^{-6}	2×10^{-9}
	500	1.45	0.003	0.145	9×10^{-5}	1.48×10^{-4}	9×10^{-8}	1.10×10^{-5}	7×10^{-9}
	1,500	1.45	0.003	0.145	9×10^{-5}	4.42×10^{-4}	3×10^{-7}	3.29×10^{-5}	2×10^{-8}
	2,100	1.45	0.003	0.145	9×10^{-5}	6.19×10^{-4}	4×10^{-7}	4.61×10^{-5}	3×10^{-8}
	3,000	1.45	0.003	0.145	9×10^{-5}	8.83×10^{-4}	5×10^{-7}	6.58×10^{-5}	4×10^{-8}
Tc/UDS/hulls waste	150	1.45	0.003	0.145	9×10^{-5}	2.19×10^{-6}	1×10^{-9}	3.54×10^{-5}	2×10^{-8}
	500	1.45	0.003	0.145	9×10^{-5}	7.39×10^{-6}	4×10^{-9}	1.19×10^{-4}	7×10^{-8}
	1,500	1.45	0.003	0.145	9×10^{-5}	2.19×10^{-5}	1×10^{-8}	3.54×10^{-4}	2×10^{-7}
	2,100	1.45	0.003	0.145	9×10^{-5}	3.07×10^{-5}	2×10^{-8}	4.96×10^{-4}	3×10^{-7}
	3,000	1.45	0.003	0.145	9×10^{-5}	4.39×10^{-5}	3×10^{-8}	7.08×10^{-4}	4×10^{-7}
GTCC LLW AND MLLW	150	1.25	8×10^{-4}	0.0624	4×10^{-5}	5.91×10^{-7}	4×10^{-10}	9.54×10^{-6}	6×10^{-9}
	500	1.25	8×10^{-4}	0.0624	4×10^{-5}	1.97×10^{-6}	1×10^{-9}	3.18×10^{-5}	2×10^{-8}
	1,500	1.25	8×10^{-4}	0.0624	4×10^{-5}	5.91×10^{-6}	4×10^{-9}	9.54×10^{-5}	6×10^{-8}
	2,100	1.25	8×10^{-4}	0.0624	4×10^{-5}	8.27×10^{-6}	5×10^{-9}	1.34×10^{-4}	8×10^{-8}
	3,000	1.25	8×10^{-4}	0.0624	4×10^{-5}	1.18×10^{-5}	7×10^{-9}	1.91×10^{-4}	1×10^{-7}
LLW AND MLLW	150	0.106	6×10^{-5}	0.0105	6×10^{-6}	2.36×10^{-7}	1×10^{-10}	4.02×10^{-6}	2×10^{-9}
	500	0.106	6×10^{-5}	0.0105	6×10^{-6}	9.97×10^{-7}	6×10^{-10}	1.34×10^{-5}	8×10^{-9}
	1,500	0.106	6×10^{-5}	0.0105	6×10^{-6}	2.36×10^{-6}	1×10^{-9}	3.82×10^{-5}	2×10^{-8}
	2,100	0.106	6×10^{-5}	0.0105	6×10^{-6}	3.30×10^{-6}	2×10^{-9}	5.35×10^{-5}	3×10^{-8}
	3,000	0.106	6×10^{-5}	0.0105	6×10^{-6}	4.73×10^{-6}	3×10^{-9}	7.63×10^{-5}	5×10^{-8}

TABLE E.2.4-7—*Per-Shipment Loading Impacts Associated with Thermal/Fast Reactor Recycle Alternative—All-Rail Option (continued)*

	Mileage	Handling Impacts				Impacts at Stops			
		Loading		Inspection		Railyard		Nearby Residents	
		Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs	Person-Rem	LCFs
Am oxide product	150	0.770	5×10^{-4}	0.320	2×10^{-4}	5.91×10^{-7}	4×10^{-10}	9.54×10^{-6}	6×10^{-9}
	500	0.770	5×10^{-4}	0.320	2×10^{-4}	1.97×10^{-6}	1×10^{-10}	3.18×10^{-5}	2×10^{-8}
	1,500	0.770	5×10^{-4}	0.320	2×10^{-4}	5.91×10^{-6}	4×10^{-9}	9.54×10^{-5}	6×10^{-8}
	2,100	0.770	5×10^{-4}	0.320	2×10^{-4}	8.27×10^{-6}	5×10^{-9}	1.34×10^{-4}	8×10^{-8}
	3,000	0.770	5×10^{-4}	0.320	2×10^{-4}	1.18×10^{-5}	7×10^{-9}	1.91×10^{-4}	1×10^{-7}
Cm oxide product	150	0.770	5×10^{-4}	0.320	2×10^{-4}	5.91×10^{-7}	4×10^{-10}	9.54×10^{-6}	6×10^{-9}
	500	0.770	5×10^{-4}	0.320	2×10^{-4}	1.97×10^{-6}	1×10^{-10}	3.18×10^{-5}	2×10^{-8}
	1,500	0.770	5×10^{-4}	0.320	2×10^{-4}	5.91×10^{-6}	4×10^{-9}	9.54×10^{-5}	6×10^{-8}
	2,100	0.770	5×10^{-4}	0.320	2×10^{-4}	8.27×10^{-6}	5×10^{-9}	1.34×10^{-4}	8×10^{-8}
	3,000	0.770	5×10^{-4}	0.320	2×10^{-4}	1.18×10^{-5}	7×10^{-9}	1.91×10^{-4}	1×10^{-7}
Recovered uranium (oxide)	150	0.769	5×10^{-4}	0.320	2×10^{-4}	2.29×10^{-5}	1×10^{-8}	1.28×10^{-6}	8×10^{-10}
	500	0.769	5×10^{-4}	0.320	2×10^{-4}	7.64×10^{-5}	5×10^{-8}	4.29×10^{-6}	3×10^{-9}
	1,500	0.769	5×10^{-4}	0.320	2×10^{-4}	2.29×10^{-4}	1×10^{-7}	1.28×10^{-5}	8×10^{-9}
	2,100	0.769	5×10^{-4}	0.320	2×10^{-4}	3.21×10^{-4}	2×10^{-7}	1.80×10^{-5}	1×10^{-8}
	3,000	0.769	5×10^{-4}	0.320	2×10^{-4}	4.58×10^{-4}	3×10^{-7}	2.57×10^{-5}	2×10^{-8}
Recovered uranium (metal)	150	0.513	3×10^{-4}	0.214	1×10^{-4}	1.91×10^{-6}	1×10^{-9}	1.18×10^{-7}	7×10^{-11}
	500	0.513	3×10^{-4}	0.214	1×10^{-4}	6.37×10^{-6}	4×10^{-9}	3.94×10^{-7}	2×10^{-10}
	1,500	0.513	3×10^{-4}	0.214	1×10^{-4}	1.91×10^{-5}	1×10^{-8}	1.18×10^{-6}	7×10^{-10}
	2,100	0.513	3×10^{-4}	0.214	1×10^{-4}	2.67×10^{-5}	2×10^{-8}	1.65×10^{-6}	1×10^{-9}
	3,000	0.513	3×10^{-4}	0.214	1×10^{-4}	3.82×10^{-5}	2×10^{-8}	2.36×10^{-6}	1×10^{-9}

Source: Tetra Tech 2008f

TABLE E.2.4-8—*Per-Shipment Incident-Free In-Transit Impacts—Thermal/Fast Reactor Recycle Alternative—All-Rail Option*

	Mileage	Crew Impacts [a]		Impacts to Public		Nonradiological Emission Fatalities
		Person-Rem	LCFs	Person-Rem	LCFs	
Cs/Sr waste	150	0.00406	2×10^{-6}	0.0329	3×10^{-5}	6.28×10^{-9}
	500	0.0135	8×10^{-6}	0.109	7×10^{-5}	2.09×10^{-8}
	1,500	0.0406	2×10^{-5}	0.336	2×10^{-4}	6.28×10^{-8}
	2,100	0.0568	3×10^{-5}	0.470	3×10^{-4}	8.79×10^{-8}
	3,000	0.0812	5×10^{-5}	0.658	4×10^{-4}	1.26×10^{-7}
Ln/fission product waste	150	0.00406	2×10^{-6}	0.0586	4×10^{-5}	6.28×10^{-9}
	500	0.0135	8×10^{-6}	0.194	1×10^{-4}	2.09×10^{-8}
	1,500	0.0406	2×10^{-5}	0.584	4×10^{-4}	6.28×10^{-8}
	2,100	0.0568	3×10^{-5}	0.817	5×10^{-4}	8.79×10^{-8}
	3,000	0.0812	5×10^{-5}	1.16	7×10^{-4}	1.26×10^{-7}
Tc/UDS/hulls waste	150	0.00406	2×10^{-6}	0.0493	3×10^{-5}	6.28×10^{-9}
	500	0.0135	8×10^{-6}	0.164	1×10^{-4}	2.09×10^{-8}
	1,500	0.0406	2×10^{-5}	0.493	3×10^{-4}	6.28×10^{-8}
	2,100	0.0568	3×10^{-5}	0.586	4×10^{-4}	8.79×10^{-8}
	3,000	0.0812	5×10^{-5}	0.986	6×10^{-4}	1.26×10^{-7}
GTCC LLW AND MLLW	150	0.00203	1×10^{-6}	0.0105	6×10^{-6}	6.28×10^{-9}
	500	0.00663	4×10^{-6}	0.0350	2×10^{-5}	2.09×10^{-8}
	1,500	0.0203	1×10^{-5}	0.105	6×10^{-5}	6.28×10^{-8}
	2,100	0.0284	2×10^{-5}	0.147	9×10^{-5}	8.79×10^{-8}
	3,000	0.0406	2×10^{-5}	0.210	1×10^{-4}	1.26×10^{-7}
LLW AND MLLW	150	8.12×10^{-4}	5×10^{-7}	0.00421	3×10^{-6}	6.28×10^{-9}
	500	0.00265	2×10^{-6}	0.0140	8×10^{-6}	2.09×10^{-8}
	1,500	0.0812	5×10^{-6}	0.0420	3×10^{-5}	6.28×10^{-8}
	2,100	0.0114	7×10^{-6}	0.0588	4×10^{-5}	8.79×10^{-8}
	3,000	0.0162	1×10^{-5}	0.0807	5×10^{-5}	1.26×10^{-7}
Am oxide product	150	0.0472	3×10^{-5}	0.00579	3×10^{-6}	6.28×10^{-9}
	500	0.0669	4×10^{-5}	0.0193	1×10^{-5}	2.09×10^{-8}
	1,500	0.123	7×10^{-5}	0.0579	3×10^{-5}	6.28×10^{-8}
	2,100	0.157	9×10^{-5}	0.0810	5×10^{-5}	8.79×10^{-8}
	3,000	0.207	1×10^{-4}	0.116	7×10^{-5}	1.26×10^{-7}
Cm oxide product	150	0.0472	3×10^{-5}	0.00579	3×10^{-6}	6.28×10^{-9}
	500	0.0669	4×10^{-5}	0.0193	1×10^{-5}	2.09×10^{-8}
	1,500	0.123	7×10^{-5}	0.0579	3×10^{-5}	6.28×10^{-8}
	2,100	0.157	9×10^{-5}	0.0810	5×10^{-5}	8.79×10^{-8}
	3,000	0.207	1×10^{-4}	0.116	7×10^{-5}	1.26×10^{-7}
Recovered uranium (oxide)	150	0.00203	1×10^{-6}	0.00579	3×10^{-6}	6.28×10^{-9}
	500	0.00663	4×10^{-6}	0.00197	1×10^{-5}	2.09×10^{-8}
	1,500	0.0203	1×10^{-5}	0.0579	3×10^{-5}	6.28×10^{-8}
	2,100	0.0284	2×10^{-5}	0.0810	5×10^{-5}	8.79×10^{-8}
	3,000	0.0406	2×10^{-5}	0.116	7×10^{-5}	1.26×10^{-7}
Recovered uranium (metal)	150	0.00203	1×10^{-6}	0.00521	3×10^{-6}	6.28×10^{-9}
	500	0.00663	4×10^{-6}	0.0177	1×10^{-5}	2.09×10^{-8}
	1,500	0.0203	1×10^{-5}	0.0521	3×10^{-5}	6.28×10^{-8}
	2,100	0.0284	2×10^{-5}	0.0729	4×10^{-5}	8.79×10^{-8}
	3,000	0.0406	2×10^{-5}	0.104	6×10^{-5}	1.26×10^{-7}

Source: Tetra Tech 2008f

[a] Crew impacts are equivalent to the impacts expected for two security escorts accompanying each shipment (see Table E.2.4-9). As provided in the Yucca Mountain SEIS (DOE 2008f) and the RADTRAN User's Manual (Weiner et al. 2006), there would be no dose to the conductors and engineer present in the locomotive. This is due to distance (up to 150 m from the source) and the shielding provided by the locomotive and the other cars between the source and the inhabitants of the locomotive. Although not all material types would require security escorts, the crew impacts provided in this table provide a conservative estimate of what could be expected.

Tables E.2.4-9 and E.2.4-10 provide the estimated incident-free impacts to escorts associated with the shipment of spent fuel and fresh transmutation and MOX fuels from the domestic programmatic alternatives, in terms of radiological exposure and additional LCFs. Table E.2.4-11 provides the nonradiological impacts to the general public due to the escort vehicle traffic. The emission fatalities values represent additional public fatalities due to increased ambient fugitive dust and gasoline or diesel exhaust emissions attributed to the escort vehicles. The collision fatalities represent additional fatalities due to accidents related to the escort vehicles.

TABLE E.2.4-9—*Per-Shipment Incident-Free Radiation Doses to Escorts—Shipments of Spent Nuclear Fuel and Fresh Transmutation Fuel—Domestic Programmatic Alternatives*

Shipment Mileage	All-Truck Scenario		All-Rail Scenario	
	Person-Rem	LCFs	Person-Rem	LCFs
150	4.13×10^{-4}	2×10^{-7}	0.00406	2×10^{-6}
500	0.00138	8×10^{-7}	0.0135	8×10^{-6}
1,500	0.00413	2×10^{-6}	0.0406	2×10^{-5}
2,100	0.00578	3×10^{-6}	0.0568	3×10^{-5}
3,000	0.00826	5×10^{-6}	0.0812	5×10^{-5}

Source: Tetra Tech 2008f
Note: Fresh transmutation fuel would only be transported by truck, as described in 10 CFR 51.52.

TABLE E.2.4-10—*Per-Shipment Incident-Free Radiation Doses to Escorts—Fresh MOX Fuel Shipments—Domestic Programmatic Alternatives*

Shipment Mileage	All-Truck Scenario	
	Person-Rem	LCFs
150	3.55×10^{-6}	2×10^{-9}
500	1.18×10^{-5}	7×10^{-9}
1,500	3.55×10^{-5}	2×10^{-8}
2,100	4.96×10^{-5}	3×10^{-8}
3,000	7.08×10^{-5}	4×10^{-8}

Source: Tetra Tech 2008f
Note: Fresh MOX fuel would only be transported by truck, as described in 10 CFR 51.52.

TABLE E.2.4-11—*Per-Shipment Nonradiological Impacts to General Population due to Escort Vehicle Traffic—Fresh and Spent Nuclear Fuel Shipments—Domestic Programmatic Alternatives*

Shipment Mileage	All-Truck Scenario		All-Rail Scenario	
	Emission Fatalities	Collision Fatalities	Emission Fatalities	Collision Fatalities
150	2.81×10^{-7}	6.13×10^{-6}	1.56×10^{-6}	1.02×10^{-5}
500	9.35×10^{-7}	2.04×10^{-5}	2.81×10^{-6}	3.41×10^{-5}
1,500	2.81×10^{-6}	6.13×10^{-5}	8.43×10^{-6}	2.65×10^{-4}
2,100	3.93×10^{-6}	8.58×10^{-5}	1.18×10^{-5}	3.71×10^{-4}
3,000	5.61×10^{-6}	1.23×10^{-4}	1.69×10^{-5}	5.30×10^{-4}

Source: Tetra Tech 2008f

E.2.5 Accident Analysis—Domestic Programmatic Alternative

The NRC developed release fractions for commercial SNF from BWR and PWR (NRC 2000a). The analysis estimated the amount of radioactive material released from a cask in an accident by multiplying the approximate release fraction by the number of fuel assemblies in a cask and the radioactivity of a SNF assembly. For this analysis, the release fractions developed in *Reexamination of Spent Fuel Shipment Risk Estimate* (NRC 2000a) for commercial PWR fuel were used, which is more conservative than the assumption of release fractions associated with BWR fuel groups. For the LWR SNF shipments, it was assumed that the same per mass nuclide inventory based on SNF inventory data provided by the AFCF NEPA Data Study, and the mass per cask, was similar for the PWR and BWR fuels. For truck shipments, the mass of PWR and BWR SNF were 2.0 MTHM and 1.8 MTHM, respectively. For the rail shipment analyses, PWR and BWR SNF masses per cask were 5.0 MTHM and 4.8 MTHM, respectively.

As stated in the *West Valley Demonstration Project (WVDP) Waste Management Final Environmental Impact Statement* (hereafter WVDP FEIS) (DOE 2004f), the two studies described above can be applied to waste types other than SNF. In the WVDP FEIS, release fractions and conditional probabilities are provided for a wide range of materials and the corresponding transportation containers. Tables E.2.5-1 through E.2.5-6 provide the conditional probabilities and release fractions associated with the domestic programmatic SNF shipments. Table E.2.5-7 and Table E.2.5-8 provide conditional probabilities and release fractions used for shipments containing HLW canisters and 9975 containers, respectively. Table E.2.5-9 provides the conditional probabilities and release fractions associated with the Class B casks used to transport fresh MOX fuel, as provided in NRC 2005c. The term “CRUD” is defined as Chalk River Undefined Deposits, which represent oxide deposits that form on the exterior of zirconium clad SNF rods. These deposits are usually composed of cobalt and iron among others.

The per-shipment accident analysis impacts for the domestic programmatic alternatives are provided in Tables E.2.5-10 and Table E.2.5-11. These per-shipment values can be multiplied by the appropriate factors to estimate the impacts of varying configurations to meet different alternatives. For the truck impact values provided in Table E.2.5-10, accident and fatality rates were calculated by multiplying the national average rates provided in Saricks and Tompkins (1999) by 1.54 and 1.67, for accidents and fatalities respectively.

Table E.2.5-12 provides the maximum foreseeable accident impacts results for the materials transported in the domestic programmatic alternatives. These impacts represent the consequences of an accident at a population center and an accident in a rural setting. Materials associated with the thermal recycle processes include the wastes generated in the separations and other processes, recovered uranium and transuranic products, LWR SNF, and MOX SNF. The fast recycle process materials include the process wastes, recovered uranium product, LWR SNF, fresh ARR fuel, and ARR SNF. The materials associated with Thorium Cycle, All-HWR, and All-HTGR Alternatives are represented by their respective SNFs, since no recycle processes are associated with these alternatives.

The analysis was based on the 21 rail accident severity categories identified in *Reexamination of Spent Fuel Shipment Risk Estimate* (NRC 2000a. Each of the 21 accident cases has an associated conditional probability of occurrence (NRC 2000a). Combining the conditional probabilities analyzed in the domestic programmatic alternatives, only the Case 4 event and the Case 20 event have occurrence frequencies greater than 1×10^{-7} per year, with expected annual frequencies of 5×10^{-6} and 3×10^{-6}, respectively (NRC 2000a).

The Case 20 event is a long-duration event high-temperature fire event that engulfs the entire cask. This event is assumed to last many hours (NRC 2000a).

The Case 4 event assumes a moderate-speed impact (30 to 60 miles per hour [48 to 97 kilometers per hour]) into a hard surface such as granite severe enough to cause failure of casks seals. This impact would be followed by an engulfing fire lasting from 0.5 hour to a few hours (NRC 2000a).

The Case 20 event was estimated to have the higher consequences and was thus assumed to be the maximum reasonably foreseeable transportation accident. As reflected in the data provided in Table E.2.5-12 the LWR and MOX SNF materials present the largest potential impacts.

For analysis of routine transportation accident risk, DOE combined the 21 accident cases for rail transport (and 19 accident cases for truck transport) into six accident categories, based on accident conditions and consequences. The six categories represent the summation of conditional probabilities and the weighted average release fractions of the associated material types.

TABLE E.2.5-1—*Conditional Probabilities and Release Fractions for Light Water Reactor, Mixed-Oxide, and Thorium Cycle Spent Nuclear Fuel Shipments—Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.06×10^{-5}	1.36×10^{-1}	4.09×10^{-9}	1.02×10^{-7}	1.02×10^{-7}	1.36×10^{-3}
3	5.86×10^{-6}	8.39×10^{-1}	1.68×10^{-5}	6.71×10^{-8}	6.71×10^{-8}	2.52×10^{-3}
4	4.95×10^{-7}	4.49×10^{-1}	1.35×10^{-6}	3.37×10^{-7}	3.37×10^{-7}	1.83×10^{-3}
5	7.49×10^{-7}	8.35×10^{-1}	3.60×10^{-5}	3.77×10^{-6}	3.77×10^{-6}	3.16×10^{-3}
6	3.00×10^{-10}	8.40×10^{-1}	2.40×10^{-5}	2.15×10^{-5}	5.01×10^{-6}	3.17×10^{-3}

Source: Jason Technologies 2001

TABLE E.2.5-2—*Conditional Probabilities and Release Fractions for Heavy Water Reactor Spent Nuclear Fuel Shipments—Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	5.66×10^{-5}	3.54×10^{-7}	2.29×10^{-8}	1.83×10^{-9}	5.71×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.60×10^{-7}	7.86×10^{-4}	1.42×10^{-7}	6.63×10^{-8}	5.80×10^{-8}	1.93×10^{-4}
5	6.99×10^{-8}	4.00×10^{-3}	7.87×10^{-5}	4.72×10^{-6}	3.20×10^{-8}	6.35×10^{-5}
6	2.24×10^{-10}	7.70×10^{-3}	2.74×10^{-4}	7.57×10^{-5}	3.68×10^{-7}	1.13×10^{-3}

Source: BMI 2007

TABLE E.2.5-3—*Conditional Probabilities and Release Fractions for High Temperature Gas-Cooled Reactor Spent Nuclear Fuel Shipments—Truck Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	0.0	0.0	0.0	0.0	0.0
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.60×10^{-7}	7.50×10^{-4}	5.63×10^{-10}	5.63×10^{-10}	5.63×10^{-10}	0.0
5	6.99×10^{-8}	0.0	0.0	0.0.	0.0	0.0
6	2.24×10^{-10}	3.52×10^{-3}	2.72×10^{-9}	2.64×10^{-9}	2.64×10^{-9}	0.0

Source: BMI 2007

TABLE E 2.5-4—*Conditional Probabilities and Release Fractions for Light Water Reactor Spent Nuclear Fuel, Mixed-Oxide Spent Nuclear Fuel, and Thorium Cycle Spent Nuclear Fuel Shipments—Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.96×10^{-1}	5.87×10^{-9}	1.34×10^{-7}	1.34×10^{-7}	1.37×10^{-3}
3	4.91×10^{-5}	8.39×10^{-1}	1.68×10^{-5}	2.52×10^{-7}	2.52×10^{-7}	9.44×10^{-3}
4	5.77×10^{-7}	8.00×10^{-1}	8.71×10^{-6}	1.32×10^{-5}	1.32×10^{-5}	4.42×10^{-3}
5	1.10×10^{-7}	8.35×10^{-1}	3.60×10^{-5}	4.63×10^{-5}	1.37×10^{-5}	5.36×10^{-3}
6	8.52×10^{-10}	8.47×10^{-1}	5.71×10^{-5}	1.43×10^{-5}	1.43×10^{-5}	1.59×10^{-2}

Source: BMI 2007

TABLE E.2.5-5—*Conditional Probabilities and Release Fractions for Heavy Water Reactor Spent Nuclear Fuel Shipments—Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	2.84×10^{-4}	1.71×10^{-6}	3.91×10^{-7}	1.10×10^{-8}	2.96×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	1.10×10^{-7}	4.00×10^{-3}	7.87×10^{-5}	1.77×10^{-5}	9.68×10^{-8}	1.61×10^{-4}
6	8.52×10^{-10}	4.68×10^{-2}	9.63×10^{-4}	2.47×10^{-4}	2.73×10^{-6}	7.17×10^{-3}

Source: BMI 2007

TABLE E.2.5-6—*Conditional Probabilities and Release Fractions for High Temperature Gas-Cooled Reactor Spent Nuclear Fuel Shipments—Rail Cask*

Accident Severity Cat.	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.9991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.02×10^{-4}	6.12×10^{-11}	6.12×10^{-11}	6.12×10^{-11}	0.0
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	4.77×10^{-3}	7.89×10^{-8}	7.89×10^{-8}	7.89×10^{-8}	0.0
5	1.10×10^{-7}	0.0	0.0	0.0	0.0	0.0
6	8.52×10^{-10}	1.70×10^{-3}	2.84×10^{-8}	2.62×10^{-8}	2.62×10^{-8}	0.0

Source: BMI 2007

TABLE E.2.5-7—*Conditional Probabilities and Release Fractions for High-Level Radioactive Waste Canister Shipments*

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.99993	0	0.99991	0
2	6.2×10^{-5}	3.4×10^{-8}	3.9×10^{-5}	6.2×10^{-8}
3	5.6×10^{-6}	0	4.9×10^{-5}	0
4	5.2×10^{-7}	2.4×10^{-7}	5.8×10^{-7}	7.9×10^{-6}
5	7.0×10^{-8}	9.3×10^{-8}	1.1×10^{-7}	9.3×10^{-8}
6	2.2×10^{-10}	3.0×10^{-7}	8.5×10^{-10}	2.7×10^{-6}

Source: DOE 2004f

TABLE E.2.5-8—*Conditional Probabilities and Release Fractions for 9975 Container Shipments*

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.99993	0	0.99991	0
2	6.2×10^{-5}	2.6×10^{-5}	3.9×10^{-5}	2.5×10^{-5}
3	5.6×10^{-6}	2.4×10^{-5}	4.9×10^{-5}	5.6×10^{-6}
4	5.2×10^{-7}	2.6×10^{-5}	5.8×10^{-7}	5.2×10^{-7}
5	7.0×10^{-8}	6.2×10^{-5}	1.1×10^{-7}	7.0×10^{-8}
6	2.2×10^{-10}	6.7×10^{-5}	8.5×10^{-10}	2.2×10^{-10}

Source: DOE 2004f

TABLE E.2.5-9—*Conditional Probabilities and Release Fractions for Class B Cask for Fresh MOX Fuel*

Severity Category	Truck	
	Conditional Probability	Release Fraction
1	0.99993	0
2	6.2×10^{-5}	6×10^{-8}
3	5.6×10^{-6}	2×10^{-7}
4	5.2×10^{-7}	2×10^{-6}
5	7.0×10^{-8}	2×10^{-5}
6	2.2×10^{-10}	2×10^{-5}

Source: NRC 2005c

TABLE E.2.5-10—*Per-Shipment Accident Impacts—Domestic Programmatic Alternative Scenarios—All-Truck Option*

Material Type	Mileage	Radiological Accident Impacts		Estimated Number of Accidents	Collision Fatalities (Nonradiological)
		Person-Rem	LCFs		
LWR SNF	150	1.24×10^{-6}	7×10^{-10}	1.14×10^{-4}	6.13×10^{-6}
	500	4.13×10^{-6}	2×10^{-9}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.25×10^{-5}	7×10^{-9}	0.00117	6.13×10^{-5}
	2,100	1.69×10^{-5}	1×10^{-8}	0.00164	8.58×10^{-5}
	3,000	2.48×10^{-5}	1×10^{-8}	0.00234	1.23×10^{-4}
MOX SNF	150	9.94×10^{-7}	6×10^{-10}	1.14×10^{-4}	6.13×10^{-6}
	500	3.31×10^{-6}	2×10^{-9}	3.89×10^{-4}	2.04×10^{-5}
	1,500	9.93×10^{-6}	6×10^{-9}	0.00117	6.13×10^{-5}
	2,100	1.39×10^{-5}	8×10^{-9}	0.00164	8.58×10^{-5}
	3,000	1.99×10^{-5}	1×10^{-8}	0.00234	1.23×10^{-4}
Thorium cycle SNF	150	6.32×10^{-8}	4×10^{-11}	1.14×10^{-4}	6.13×10^{-6}
	500	2.10×10^{-7}	1×10^{-10}	3.89×10^{-4}	2.04×10^{-5}
	1,500	6.31×10^{-7}	4×10^{-10}	0.00117	6.13×10^{-5}
	2,100	8.83×10^{-7}	5×10^{-10}	0.00164	8.58×10^{-5}
	3,000	1.26×10^{-6}	8×10^{-10}	0.00234	1.23×10^{-4}
HWR SNF	150	2.14×10^{-8}	1×10^{-11}	1.14×10^{-4}	6.13×10^{-6}
	500	7.12×10^{-8}	4×10^{-11}	3.89×10^{-4}	2.04×10^{-5}
	1,500	2.14×10^{-7}	1×10^{-10}	0.00117	6.13×10^{-5}
	2,100	3.00×10^{-7}	2×10^{-10}	0.00164	8.58×10^{-5}
	3,000	4.27×10^{-7}	3×10^{-10}	0.00234	1.23×10^{-4}
HTGR SNF	150	3.75×10^{-12}	2×10^{-15}	1.14×10^{-4}	6.13×10^{-6}
	500	1.25×10^{-11}	8×10^{-15}	3.89×10^{-4}	2.04×10^{-5}
	1,500	3.75×10^{-11}	2×10^{-14}	0.00117	6.13×10^{-5}
	2,100	5.24×10^{-11}	3×10^{-14}	0.00164	8.58×10^{-5}
	3,000	7.48×10^{-11}	4×10^{-14}	0.00234	1.23×10^{-4}
Fresh Transmutation Fuel	150	9.91×10^{-7}	6×10^{-10}	1.14×10^{-4}	6.13×10^{-6}
	500	3.30×10^{-6}	2×10^{-9}	3.89×10^{-4}	2.04×10^{-5}
	1,500	9.85×10^{-6}	6×10^{-9}	0.00117	6.13×10^{-5}
	2,100	1.39×10^{-5}	8×10^{-9}	0.00164	8.58×10^{-5}
	3,000	1.97×10^{-5}	1×10^{-8}	0.00234	1.23×10^{-4}
Fresh MOX Fuel	150	1.06×10^{-11}	6×10^{-15}	1.14×10^{-4}	6.13×10^{-6}
	500	3.54×10^{-11}	2×10^{-14}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.06×10^{-10}	6×10^{-14}	0.00117	6.13×10^{-5}
	2,100	1.49×10^{-10}	9×10^{-14}	0.00164	8.58×10^{-5}
	3,000	2.12×10^{-10}	1×10^{-13}	0.00234	1.23×10^{-4}
Am oxide product	150	2.93×10^{-8}	2×10^{-11}	1.14×10^{-4}	6.13×10^{-6}
	500	9.74×10^{-8}	6×10^{-11}	3.89×10^{-4}	2.04×10^{-5}
	1,500	2.92×10^{-7}	2×10^{-10}	0.00117	6.13×10^{-5}
	2,100	4.10×10^{-7}	2×10^{-10}	0.00164	8.58×10^{-5}
	3,000	5.84×10^{-7}	4×10^{-10}	0.00234	1.23×10^{-4}
Cm oxide product	150	1.77×10^{-7}	1×10^{-10}	1.14×10^{-4}	6.13×10^{-6}
	500	5.90×10^{-7}	4×10^{-10}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.76×10^{-6}	1×10^{-9}	0.00117	6.13×10^{-5}
	2,100	2.48×10^{-6}	1×10^{-9}	0.00164	8.58×10^{-5}
	3,000	3.52×10^{-6}	2×10^{-9}	0.00234	1.23×10^{-4}
Pu/Np oxide product	150	8.19×10^{-8}	4×10^{-11}	1.14×10^{-4}	6.13×10^{-6}
	500	2.73×10^{-7}	2×10^{-10}	3.89×10^{-4}	2.04×10^{-5}
	1,500	8.14×10^{-7}	5×10^{-10}	0.00117	6.13×10^{-5}
	2,100	1.15×10^{-6}	7×10^{-10}	0.00164	8.58×10^{-5}
	3,000	1.63×10^{-6}	1×10^{-9}	0.00234	1.23×10^{-4}

TABLE E.2.5-10—*Per-Shipment Accident Impacts—Domestic Programmatic Alternative Scenarios—All-Truck Option (continued)*

Material Type	Mileage	Radiological Accident Impacts		Estimated Number of Accidents	Collision Fatalities (Nonradiological)
		Person-Rem	LCFs		
Consolidated TRU/U product	150	9.09×10^{-9}	5×10^{-12}	1.14×10^{-4}	6.13×10^{-6}
	500	3.03×10^{-8}	2×10^{-11}	3.89×10^{-4}	2.04×10^{-5}
	1,500	9.03×10^{-8}	5×10^{-11}	0.00117	6.13×10^{-5}
	2,100	1.27×10^{-7}	8×10^{-11}	0.00164	8.58×10^{-5}
	3,000	1.81×10^{-7}	1×10^{-10}	0.00234	1.23×10^{-4}
Cs/Sr waste	150	7.11×10^{-7}	4×10^{-10}	1.14×10^{-4}	6.13×10^{-6}
	500	2.36×10^{-6}	1×10^{-9}	3.89×10^{-4}	2.04×10^{-5}
	1,500	7.09×10^{-6}	4×10^{-9}	0.00117	6.13×10^{-5}
	2,100	9.69×10^{-6}	6×10^{-9}	0.00164	8.58×10^{-5}
	3,000	1.42×10^{-5}	9×10^{-9}	0.00234	1.23×10^{-4}
Ln/fission products waste	150	2.06×10^{-9}	1×10^{-12}	1.14×10^{-4}	6.13×10^{-6}
	500	6.87×10^{-9}	4×10^{-12}	3.89×10^{-4}	2.04×10^{-5}
	1,500	2.06×10^{-8}	1×10^{-11}	0.00117	6.13×10^{-5}
	2,100	2.92×10^{-8}	2×10^{-11}	0.00164	8.58×10^{-5}
	3,000	4.12×10^{-8}	2×10^{-11}	0.00234	1.23×10^{-4}
Tc/UDS/hulls waste	150	1.92×10^{-8}	1×10^{-11}	1.14×10^{-4}	6.13×10^{-6}
	500	6.38×10^{-8}	4×10^{-11}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.92×10^{-7}	1×10^{-10}	0.00117	6.13×10^{-5}
	2,100	2.14×10^{-7}	2×10^{-10}	0.00164	8.58×10^{-5}
	3,000	3.83×10^{-7}	2×10^{-10}	0.00234	1.23×10^{-4}
GTCC LLW AND MLLW	150	1.17×10^{-10}	7×10^{-14}	1.14×10^{-4}	6.13×10^{-6}
	500	3.88×10^{-10}	2×10^{-13}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.16×10^{-9}	7×10^{-13}	0.00117	6.13×10^{-5}
	2,100	1.62×10^{-9}	9×10^{-13}	0.00164	8.58×10^{-5}
	3,000	2.33×10^{-9}	1×10^{-12}	0.00234	1.23×10^{-4}
Fast reactor SNF	150	1.02×10^{-4}	6×10^{-8}	1.14×10^{-4}	6.13×10^{-6}
	500	3.40×10^{-4}	2×10^{-7}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.02×10^{-3}	6×10^{-7}	0.00117	6.13×10^{-5}
	2,100	1.43×10^{-3}	9×10^{-7}	0.00164	8.58×10^{-5}
	3,000	2.04×10^{-3}	1×10^{-6}	0.00234	1.23×10^{-4}
Recovered uranium oxides	150	9.87×10^{-14}	6×10^{-17}	1.14×10^{-4}	6.13×10^{-6}
	500	3.28×10^{-13}	2×10^{-16}	3.89×10^{-4}	2.04×10^{-5}
	1,500	9.85×10^{-13}	6×10^{-16}	0.00117	6.13×10^{-5}
	2,100	1.38×10^{-12}	8×10^{-16}	0.00164	8.58×10^{-5}
	3,000	1.97×10^{-12}	1×10^{-15}	0.00234	1.23×10^{-4}
Recovered uranium metal	150	1.11×10^{-13}	7×10^{-17}	1.14×10^{-4}	6.13×10^{-6}
	500	3.70×10^{-13}	2×10^{-16}	3.89×10^{-4}	2.04×10^{-5}
	1,500	1.11×10^{-12}	7×10^{-16}	0.00117	6.13×10^{-5}
	2,100	1.55×10^{-12}	9×10^{-16}	0.00164	8.58×10^{-5}
	3,000	2.22×10^{-12}	1×10^{-15}	0.00234	1.23×10^{-4}

Source: Tetra Tech 2008f

TABLE E.2.5-11—*Per-Shipment Accident Impacts—Domestic Programmatic Alternative Scenarios—All-Rail Option*

Material Type	Mileage	Radiological Accident Impacts		Estimated Number of Accidents	Collision Fatalities (Nonradiological)
		Person-Rem	LCFs		
LWR SNF	150	9.43×10^{-7}	6×10^{-10}	2.65×10^{-5}	1×10^{-5}
	500	3.13×10^{-6}	2×10^{-9}	8.84×10^{-5}	3×10^{-5}
	1,500	9.37×10^{-6}	6×10^{-9}	2.65×10^{-4}	1×10^{-4}
	2,100	1.31×10^{-5}	8×10^{-9}	3.71×10^{-4}	1×10^{-4}
	3,000	1.87×10^{-5}	1×10^{-8}	5.30×10^{-4}	2×10^{-4}
MOX SNF	150	3.14×10^{-6}	2×10^{-9}	2.65×10^{-5}	1×10^{-5}
	500	1.04×10^{-5}	6×10^{-9}	8.84×10^{-5}	3×10^{-5}
	1,500	3.12×10^{-5}	2×10^{-9}	2.65×10^{-4}	1×10^{-4}
	2,100	4.37×10^{-5}	3×10^{-9}	3.71×10^{-4}	1×10^{-4}
	3,000	6.24×10^{-5}	4×10^{-8}	5.30×10^{-4}	2×10^{-4}
Thorium cycle SNF	150	3.90×10^{-7}	2×10^{-10}	2.65×10^{-5}	1×10^{-5}
	500	1.30×10^{-6}	8×10^{-10}	8.84×10^{-5}	3×10^{-5}
	1,500	3.88×10^{-6}	2×10^{-9}	2.65×10^{-4}	1×10^{-4}
	2,100	5.43×10^{-6}	3×10^{-9}	3.71×10^{-4}	1×10^{-4}
	3,000	7.76×10^{-6}	5×10^{-8}	5.30×10^{-4}	2×10^{-4}
HWR SNF	150	5.55×10^{-7}	3×10^{-10}	2.65×10^{-5}	1×10^{-5}
	500	1.84×10^{-6}	1×10^{-9}	8.84×10^{-5}	3×10^{-5}
	1,500	5.52×10^{-6}	3×10^{-9}	2.65×10^{-4}	1×10^{-4}
	2,100	7.73×10^{-6}	5×10^{-9}	3.71×10^{-4}	1×10^{-4}
	3,000	1.10×10^{-5}	7×10^{-9}	5.30×10^{-4}	2×10^{-4}
HTGR SNF	150	9.45×10^{-10}	6×10^{-13}	2.65×10^{-5}	1×10^{-5}
	500	3.13×10^{-9}	2×10^{-12}	8.84×10^{-5}	3×10^{-5}
	1,500	9.39×10^{-9}	6×10^{-12}	2.65×10^{-4}	1×10^{-4}
	2,100	1.31×10^{-8}	8×10^{-12}	3.71×10^{-4}	1×10^{-4}
	3,000	1.88×10^{-8}	1×10^{-11}	5.30×10^{-4}	2×10^{-4}
Am oxide product	150	2.78×10^{-6}	2×10^{-9}	2.65×10^{-5}	1×10^{-5}
	500	9.28×10^{-6}	6×10^{-9}	8.84×10^{-5}	3×10^{-5}
	1,500	2.80×10^{-5}	2×10^{-8}	2.65×10^{-4}	1×10^{-4}
	2,100	3.89×10^{-5}	2×10^{-8}	3.71×10^{-4}	1×10^{-4}
	3,000	5.59×10^{-5}	3×10^{-8}	5.30×10^{-4}	2×10^{-4}
Cm oxide product	150	1.14×10^{-5}	7×10^{-9}	2.65×10^{-5}	1×10^{-5}
	500	3.81×10^{-5}	2×10^{-8}	8.84×10^{-5}	3×10^{-5}
	1,500	1.15×10^{-4}	7×10^{-8}	2.65×10^{-4}	1×10^{-4}
	2,100	1.59×10^{-4}	1×10^{-7}	3.71×10^{-4}	1×10^{-4}
	3,000	2.29×10^{-4}	1×10^{-7}	5.30×10^{-4}	2×10^{-4}
Cs/Sr waste	150	6.06×10^{-6}	4×10^{-9}	1.33×10^{-5}	5.12×10^{-6}
	500	2.01×10^{-5}	1×10^{-8}	4.42×10^{-5}	1.71×10^{-5}
	1,500	6.04×10^{-5}	4×10^{-8}	1.33×10^{-4}	5.12×10^{-5}
	2,100	8.46×10^{-5}	5×10^{-8}	1.86×10^{-4}	7.17×10^{-5}
	3,000	1.21×10^{-4}	7×10^{-8}	2.65×10^{-4}	1.02×10^{-4}

TABLE E.2.5-11—*Per-Shipment Accident Impacts—Domestic Programmatic Alternative Scenarios—All-Rail Option (continued)*

Material Type	Mileage	Radiological Accident Impacts		Estimated Number of Accidents	Collision Fatalities (Nonradiological)
		Person-Rem	LCFs		
Ln/fission products waste	150	5.02×10^{-7}	3×10^{-10}	1.33×10^{-5}	5.12×10^{-6}
	500	1.67×10^{-6}	1×10^{-9}	4.42×10^{-5}	1.71×10^{-5}
	1,500	5.01×10^{-6}	3×10^{-9}	1.33×10^{-4}	5.12×10^{-5}
	2,100	7.05×10^{-6}	4×10^{-9}	1.86×10^{-4}	7.17×10^{-5}
	3,000	1.00×10^{-5}	6×10^{-9}	2.65×10^{-4}	1.02×10^{-4}
Tc/UDS/hulls waste	150	7.18×10^{-7}	4×10^{-10}	1.33×10^{-5}	5.12×10^{-6}
	500	2.38×10^{-6}	1×10^{-9}	4.42×10^{-5}	1.71×10^{-5}
	1,500	7.16×10^{-6}	4×10^{-9}	1.33×10^{-4}	5.12×10^{-5}
	2,100	1.00×10^{-5}	6×10^{-9}	1.86×10^{-4}	7.17×10^{-5}
	3,000	1.43×10^{-5}	9×10^{-9}	2.65×10^{-4}	1.02×10^{-4}
GTCC LLW AND MLLW	150	2.98×10^{-8}	2×10^{-11}	1.33×10^{-5}	5.12×10^{-6}
	500	9.91×10^{-8}	6×10^{-11}	4.42×10^{-5}	1.71×10^{-5}
	1,500	2.97×10^{-7}	2×10^{-10}	1.33×10^{-4}	5.12×10^{-5}
	2,100	5.56×10^{-7}	3×10^{-10}	1.86×10^{-4}	7.17×10^{-5}
	3,000	5.94×10^{-7}	4×10^{-10}	2.65×10^{-4}	1.02×10^{-4}
Fast reactor SNF	150	4.63×10^{-5}	3×10^{-8}	1.33×10^{-5}	5.12×10^{-6}
	500	1.54×10^{-4}	9×10^{-8}	4.42×10^{-5}	1.71×10^{-5}
	1,500	4.61×10^{-4}	3×10^{-7}	1.33×10^{-4}	5.12×10^{-5}
	2,100	6.45×10^{-4}	4×10^{-7}	1.86×10^{-4}	7.17×10^{-5}
	3,000	9.22×10^{-4}	6×10^{-7}	2.65×10^{-4}	1.02×10^{-4}
Recovered uranium oxide	150	9.24×10^{-12}	6×10^{-15}	1.33×10^{-5}	5.12×10^{-6}
	500	3.07×10^{-11}	2×10^{-14}	4.42×10^{-5}	1.71×10^{-5}
	1,500	4.13×10^{-11}	2×10^{-14}	1.33×10^{-4}	5.12×10^{-5}
	2,100	5.78×10^{-11}	3×10^{-14}	1.86×10^{-4}	7.17×10^{-5}
	3,000	1.84×10^{-10}	1×10^{-13}	2.65×10^{-4}	1.02×10^{-4}
Recovered uranium metal	150	3.68×10^{-11}	1×10^{-14}	1.33×10^{-5}	5.12×10^{-6}
	500	1.23×10^{-10}	4×10^{-14}	4.42×10^{-5}	1.71×10^{-5}
	1,500	3.66×10^{-10}	1×10^{-13}	1.33×10^{-4}	5.12×10^{-5}
	2,100	5.12×10^{-10}	2×10^{-13}	1.86×10^{-4}	7.17×10^{-5}
	3,000	7.32×10^{-10}	3×10^{-13}	2.65×10^{-4}	1.02×10^{-4}

Source: Tetra Tech 2008f

TABLE E.2.5-12—*Maximum Reasonably Foreseeable Accident Impacts—Domestic Programmatic Alternatives*

Material Type	Impact Scenario	Accident Exposure (person-rem)		Exposure Impacts (LCFs)	
		Acute	Total	Acute	Total
LWR SNF [a,b]	Rural	5.85	18.4	0.0035	0.011
	Urban	4680	1.47×10^{4}	2.81	8.81
	MEI	10.4	32.3	0.0062	0.019
MOX SNF [a]	Rural	14.1	40.0	0.0085	0.024
	Urban	1.13×10^{4}	3.19×10^{4}	6.80	19.2
	MEI	24.1	135	0.0144	0.081
Thorium Cycle SNF [c]	Rural	0.404	1.64	0.194	0.786
	Urban	323	1310	1.99	4.09
	MEI	0.996	2.78	5.98×10^{-4}	0.00167
HWR SNF [d]	Rural	0.374	0.831	2.24×10^{-4}	3.99×10^{-4}
	Urban	300	665	0.180	0.399
	MEI	0.635	2.19	3.81×10^{-4}	0.00131
HTGR SNF [e]	Rural	0.344	0.574	2.07×10^{-4}	3.44×10^{-4}
	Urban	275	460	0.165	0.276
	MEI	0.583	1.63	3.50×10^{-4}	9.81×10^{-4}
Fast reactor SNF [b]	Rural	0.869	1.87	5.21×10^{-4}	0.0011
	Urban	695	1495	0.417	0.897
	MEI	1.13	2.62	6.78×10^{-4}	0.0016
Fresh Transmutation fuel	Rural	1.34	2.16	8.04×10^{-4}	0.00130
	Urban	1,060	1,730	0.639	1.04
	MEI	2.27	3.66	0.00136	0.00220
Fresh MOX fuel	Rural	0.155	0.250	9.30×10^{-5}	1.50×10^{-4}
	Urban	123	200	0.0740	0.120
	MEI	0.269	0.487	1.58×10^{-4}	2.92×10^{-4}
Am oxide product	Rural	0.0787	4.78	4.72×10^{-5}	0.0611
	Urban	62.9	102	0.0378	0.0611
	MEI	0.133	0.215	7.98×10^{-5}	1.29×10^{-4}
Cm oxide product	Rural	0.306	18.3	1.84×10^{-4}	0.0110
	Urban	245	396	0.147	0.238
	MEI	0.519	0.838	3.11×10^{-4}	5.03×10^{-4}
Pu/Np oxide product	Rural	0.114	6.87	6.84×10^{-5}	0.00412
	Urban	91.0	148	0.0885	0.132
	MEI	0.193	0.312	1.16×10^{-4}	1.87×10^{-4}
Consolidated TRU/U product	Rural	0.274	16.3	1.64×10^{-4}	0.00978
	Urban	219	353	0.132	0.212
	MEI	0.465	0.749	2.79×10^{-4}	4.49×10^{-4}
Recovered uranium oxides [a]	Rural	5.76×10^{-5}	6.63×10^{-5}	3.44×10^{-8}	3.98×10^{-8}
	Urban	0.0247	0.0318	1.48×10^{-5}	1.91×10^{-5}
	MEI	2.52×10^{-5}	4.03×10^{-5}	1.51×10^{-8}	2.42×10^{-8}
Recovered uranium metal [a]	Rural	7.00×10^{-4}	0.00112	4.20×10^{-7}	6.72×10^{-7}
	Urban	0.549	0.885	3.29×10^{-4}	5.31×10^{-4}
	MEI	0.00115	0.00186	6.90×10^{-7}	1.12×10^{-6}
Tc/UDS/hulls waste [a]	Rural	1.73	2.80	0.00104	0.00168
	Urban	1381	2235	0.829	1.34
	MEI	2.93	4.74	0.00176	0.00284
Fission Product Wastes [a]	Rural	0.404	1.82	2.42×10^{-4}	0.00109
	Urban	323	1455	0.194	0.873
	MEI	0.686	3.08	4.12×10^{-4}	0.00185

TABLE E.2.5-12—*Maximum Reasonably Foreseeable Accident Impacts— Domestic Programmatic Alternatives (continued)*

Material Type	Impact Scenario	Accident Exposure (person-rem)		Exposure Impacts (LCFs)	
		Acute	Total	Acute	Total
Cs/Sr Wastes [a]	Rural	0.00330	1.56	1.98×10^{-6}	9.36×10^{-4}
	Urban	26.4	1244	0.0158	0.746
	MEI	0.0565	2.64	3.39×10^{-5}	0.00158
GTCC LLW AND MLLW [a,b]	Rural	0.0136	0.0560	8.16×10^{-6}	3.36×10^{-5}
	Urban	10.9	44.8	0.00652	0.0269
	MEI	0.0231	0.0950	1.39×10^{-5}	5.70×10^{-5}

Source: Tetra Tech 2008f
[a] These materials or wastes are associated with alternatives utilizing thermal recycling processes (Fast/Thermal Reactor Recycle and Thermal Reactor Recycle Alternatives).
[b] These materials are associated with alternatives utilizing fast recycling processes.
[c] SNF associated with the Thorium Alternative.
[d] SNF associated with the all-HWR Alternative.
[e] SNF associated with the all-HTGR Alternative.

E.3 INTERNATIONAL TRANSPORTATION ANALYSIS

E.3.1 Routing Analysis for International Shipments

As described in Chapter 7, DOE analyzed the transportation impacts associated with the shipment of nuclear materials and wastes associated with the overseas construction, operation, and waste management of 1 GWe capacity in LWR reactors, although other reactor types are also possible. SNF generated in these reactors could be transported back to the United States or to a third party partner nation. The SNF could be disposed in a geologic repository, or it could be reprocessed. If reprocessed, the resulting HLW could be transported back to the user nation or to an international partner country.

Within the United States, the affected environment could be determined by the fuel fabrication facility location, the specific port of exit for the fuel rod assemblies, the specific port of entry for the SNF, the location of any SNF recycling center used, the location of any future repository, and the specific port of exit for any waste returning to a foreign nation. To date, these locations have not been identified. Once these facilities have been identified, transportation routes between them would be determined and specific environmental impacts identified. Areas impacted include the transportation routes, the ports and the surrounding areas around these routes and ports.

Domestic transportation was assumed to follow the routing parameters associated with the domestic alternatives analysis provided in the previous sections of this appendix. For the domestic transportation portions of the international shipments (fresh fuel shipments from the fuel fabrication facility to the port and spent fuel from the port to the recycling center), the 500-mile distance was assumed.

To determine the distance and voyage times between the international ports, DOE determined a shipping route that would best represent the maximum distance and voyage time for an international shipment from a U.S. port. For analysis purposes, the voyage time was rounded up to the nearest day (WSR 2007). Transportation between the United States and international port was estimated to be 7,200 mi (11,600 km) long and estimated to require approximately 31 days at sea.

E.3.2 International Program Shipments

For purposes of analysis, the international shipments were assumed to support the implementation and operation of LWRs. International shipments could involve shipment of materials associated with other nuclear reactor types. The fresh LWR fuel assemblies destined for the international reactors would be enriched to approximately 3 percent U-235. The external dose rate of the fresh fuel containers was assumed to be 0.0521 mrem/hr at a distance of 6.6 ft (2 m). It was assumed that the SNF transported would consist of fuel with a burnup of 100 GWd/MTU, with a minimum of 5 years cooling. The end-of-life effective enrichment is approximately 2.6 percent. The nuclide inventory is provided in Appendix 2 of the AFCF NEPA Data Study (WGI 2008a). LWR SNF would assume an external dose rate of 10 mrem/hr at a distance of 6.6 ft (2 m). All assemblies are assumed to be transported in GA-4 and NLI-10 casks for truck and rail shipments respectively. All waste streams from the recycling processes would use the same containers assumed for the domestic alternatives considered.

E.3.3 Loading and Inspection Impacts and Incident-Free Impacts of International Shipments

The primary effect of incident-free marine transport of fuel assemblies would be on the crew of the ships used to carry the casks. Due to the protective qualities of the transport cask, members of the general public and marine life would not receive any measurable dose from the fuel assemblies during marine transport. In addition to the protection provided by the transportation casks, further protection for the public and marine life is provided by the ship's structure. Under incident-free conditions of transport, public exposure would be limited to the ship's crew, and the ship's crew exposure would be limited to only those crew members exposed during loading and offloading of casks and to crew members who are required to inspect cargo on a daily basis to ensure secure stowage and the vessel.

While loading the fuel assemblies on board ships, inspectors, dockworkers, longshoremen, and crane operators would be exposed to radiation. This exposure is based on the regulatory limits of the NRC/DOT certified cask. Accordingly, it is expected that the exposure impacts would be the same for the returning SNF and the fresh fuel shipments. Based on existing loading operations, it is assumed that:

- Five handlers would be involved in the loading operation at a distance of 16 ft (5 m) from the source.
- Four staging personnel would be involved at a distance of 33 ft (10 m) from the source.
- One crane operator would be involved at a distance of 82 ft (25 m) from the source.
- One inspector is assumed to be present after loading at a distance of 6.6 ft (2 m) for a period of 4 hours.

In transit, inspections would be made daily requiring 6 hours of exposure at a distance of 6.6 ft (2 m). In addition, it is assumed that a chief mate would be at a distance of 82 ft (25 m) and a bosun at a distance of 33 ft (10 m) during the loading and for brief periods during each day of the voyage.

While the reactor fuel is onboard, individuals coming into close proximity of the casks, such as sailors on watch, or sailors performing routine inspections, would receive doses of radiation. The doses are a function of the time of transportation. As mentioned above, the shipment between the United States and international port is assumed to be 30 days.

E.4 SUMMARY OF ASSUMPTIONS USED IN TRANSPORTATION ANALYSES

Table E.4-1 provides a summary of the assumptions applied to the transportation analyses conducted for this PEIS. Where applicable, these assumptions were consistent with the analyses performed for the Yucca Mountain SEIS transportation assessments.

Table E.4-1 provides the assumptions for six assessment categories

1. Routing
2. Packaging/shipping configuration
3. Loading and inspection impacts
4. Dose scenarios associated with incident-free transportation
5. Transportation accident risks
6. Severe transportation accident impacts

TABLE E.4-1—*Summary of Transportation Analysis Assumptions*

1. Routing		
Parameter	**Rationale**	**References**
Distances	Route characteristics for the 61 origin sites and five destination sites considered in the Spent Nuclear Fuel EIS were used to calculate the percentage breakdown of rural, suburban, and urban population zones for the truck and rail scenarios (DOE 1995e). These percentages were applied to distances analyzed. These distances were developed based on analysis of the shipment characteristics assessed in the Yucca Mountain FEIS (DOE 2002i). The minimum shipment in this document was approximately 150 miles. The maximum was approximately 3,000 miles, with a median distance of 2,100 miles (SNL 2005).	DOE 1995e, DOE 2002i, SNL 2005
Population density	Average population densities for the rural, suburban, and urban population zones were calculated for the Spent Nuclear Fuel EIS data set described above for the truck and rail scenarios.	DOE 1995e

2. Packaging/Shipping Configuration

Truck Shipments

Material	Nuclide Inventory Source	Container	Mass or Volume per Container [a]	Containers per Shipment	Mass or Volume per Shipment	External Exposure Rate (mrem/hr at 2 m)
LWR spent fuel	WGI 2008a	GA-4/9 cask	2 MTHM	1	2 MTHM	10
Fast reactor spent fuel	WGI 2008a	NLI-1/2 cask	0.4 MTHM	1	0.4 MTHM	10
Thorium cycle spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel canister	0.6525 MTHM	1	0.6525 MTHM	10
MOX spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel canister	0.75 MTHM	1	0.75 MTHM	10
HWR spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel canister	1.58 MTHM	1	1.58 MTHM	10
HTGR spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel canister	0.02067 MTHM	1	0.02067 MTHM	10
Fresh transmutation fuel	WGI 2008a	NLI-1/2 cask	0.4 MTHM	1	0.4 MTHM	10
Fresh MOX fuel	NRC 2005c	Class B cylindrical cask	1.37 MTHM	1	1.37 MTHM	2.52
Fresh LWR fuel	Nuclide inventory not currently available	Not specified	6 MTHM	1	6 MTHM	0.0521
Fresh thorium fuel	Nuclide inventory not currently available	Not specified	1.7 MTHM	1	1.7 MTHM	0.0521
Fresh HWR fuel	Nuclide inventory not currently available	Not specified	3.24 MTHM	1	3.24 MTHM	0.0521
Fresh HTGR fuel	Nuclide inventory not currently available	Not specified	0.307 MTHM	1	0.307 MTHM	0.0521

TABLE E.4-1—*Summary of Transportation Analysis Assumptions (continued)*

2. Packaging/Shipping Configuration						
Truck Shipments						
Material	**Nuclide Inventory Source**	**Container**	**Mass or Volume per Container** [a]	**Containers per Shipment**	**Mass or Volume per Shipment**	**External Exposure Rate (mrem/hr at 2 m)**
Am oxide product	WGI 2008a	Class B drum-like containers	1.39 kg	25	34.8 kg	5
Cm oxide product	WGI 2008a	Class B drum-like containers	0.407 kg	25	10.2 kg	5
Pu/Np oxide product	WGI 2008a	Class B drum-like containers	5.00 kg	25	125 kg	5
TRU/U product	WGI 2008a	Class B drum-like containers	3.51 kg	25	87.7 kg	5
Cs/Sr waste	WGI 2008a, WGI 2008c	Waste can (3" IDx10' long)	0.067 m^3	1	0.067 m^3	10
Tc/UDS/hulls waste	WGI 2008a	HLW canister [c]	0.77 m^3	1	0.77 m^3	10
Ln/fission product waste	WGI 2008a, WSRC 2008a	HLW canister [c]	1.29 m^3	1	1.29 m^3	10
GTCC-LLW AND MLLW	WGI 2008a, WSRC 2008a	HLW canister [c]	0.79 m^3	1	0.79 m^3	10
LLW AND MLLW	WGI 2008a, WSRC 2008a	B-25 box	2.55 m^3	12	30.60 m^3	2
Uranium oxide product	WGI 2008a	Class B drum	13.5 kg (total U)	15	337.5 kg	5
Uranium metal product	WGI 2008a	Class B drum	17.2 kg	18	430 kg	5
Rail shipments						
Material	**Nuclide Inventory Source**	**Container**	**Mass or Volume per Container** [a]	**Containers per Shipment** [d]	**Mass or Volume per Shipment**	**External Exposure Rate (mrem/hr)**
LWR spent fuel	WGI 2008a	NLI-10/24 cask	5 MTHM	5	25 MTHM	10
Fast reactor spent fuel	WGI 2008a	GA-4/9 cask	0.4 MTHM	5	2 MTHM	10
Thorium cycle spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel cask [e]	5.8725 MTHM	5	29.36 MTHM	10
MOX spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel cask [e]	6.75 MTHM	5	33.7 MTHM	10
HWR spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel cask [e]	14.22 MTHM	5	71.1 MTHM	10
HTGR spent fuel [b]	DOE 2004j, BMI 2007	DOE spent fuel cask [e]	0.186 MTHM	5	0.93 MTHM	10
Am oxide product	WGI 2008a	Class B drum-like containers	1.39 kg	125	174 kg	5

TABLE E.4-1—*Summary of Transportation Analysis Assumptions (continued)*

Rail shipments						
Material	**Nuclide Inventory Source**	**Container**	**Mass or Volume per Container [a]**	**Containers per Shipment [d]**	**Mass or Volume per Shipment**	**External Exposure Rate (mrem/hr)**
Cm oxide product	WGI 2008a	Class B drum-like containers	0.407 kg	125	51.0 kg	5
Cs/Sr waste	WGI 2008a, WGI 2008c	Waste can (3" IDx10' long)	0.067 m^3	5	0.333 m^3	10
Tc/UDS/hulls waste	WGI 2008a	HLW canister [c]	0.77 m^3	5	3.85 m	10
Ln/fission product waste	WGI 2008a, WSRC 2008a	HLW canister [c]	1.29 m^3	5	6.45 m^3	10
GTCC-LLW AND MLLW	WGI 2008a, WSRC 2008a	HLW canister [c]	0.79 m^3	5	19.75 m^3	10
LLW AND MLLW	WGI 2008a, WSRC 2008a	B-25 box	2.55 m^3	60	153 m^3	2
Uranium oxide product	WGI 2008a	Class B drum	13.5 kg (total U)	75	1687.5 kg	5
Uranium metal product	WGI 2008a	Class B drum	17.2 kg	90	2150 kg	5

3. Per-Shipment Loading and Inspection Exposure Impacts

Truck Shipments			
Material	**Loading Exposure (person-rem)**	**Inspection Exposure [f] (person-rem)**	**Loading Exposure Rationale**
Spent fuel [g]	0.432	0.0738	The loading exposures assumed in the GNEP PEIS are the same assumed in the Yucca Mountain SEIS, which are based on actual exposure values provided in industry documents detailing loading of commercial spent fuel. Assumes a crew of 13 workers for a 10-hour period.
Cs/Sr waste	0.821	0.0205	For this waste stream and the other wastes/materials listed below, estimation of loading impacts was based on the size and number of packages per load. The exposure impacts reflect RADTRAN calculation for the worker population at a distance of 2 m and exposure rates provided above. For Cs/Sr, it was assumed that five workers would take eight hours to load a truck shipment.
Tc/UDS/hulls waste	0.325	0.0162	Assumes a crew of five workers for a four-hour period.
Ln/fission product waste	0.326	0.0163	Assumes a crew of five workers for a four-hour period.
GTCC-LLW AND MLLW	0.125	0.00625	Assumes a crew of five workers for a four-hour period.
LLW AND MLLW	0.0212	0.00210	Assumes a crew of five workers for a 12-hour period.
Fresh transmutation fuel	0.432	0.0738	Assumes a crew of 13 workers for a 10-hour period

TABLE E.4-1—*Summary of Transportation Analysis Assumptions (continued)*

Truck Shipments			
Material	**Loading Exposure (person-rem)**	**Inspection Exposure [f] (person-rem)**	**Loading Exposure Rationale**
Fresh MOX fuel	0.109	0.0186	Assumes a crew of 13 workers for a 10-hour period
Fresh LWR, thorium, HWR, HTGR fuel	0.0225	0.00384	Assumes a crew of 13 workers for a 10-hour period
Am, Cm, and Pu/Np oxide products	0.154	0.0641	Assumes a crew of five workers for a 12-hour period
TRU/U oxide product	0.154	0.0641	Assumes a crew of five workers for a 12-hour period
Uranium oxide product	0.154	0.0641	Assumes a crew of five workers for a 12-hour period.
Uranium metal product	0.103	0.0461	Assumes a crew of five workers for an eight-hour period.
Rail Shipments			
Material	**Loading Exposure (person-rem)**	**Inspection Exposure [f,h] (person-rem)**	**Loading Exposure Rationale**
Spent fuel [g]	3.32	0.185	The loading exposures assumed in the GNEP PEIS are the same assumed in the Yucca Mountain SEIS, which are based on actual exposure values provided in industry documents detailing loading of commercial spent fuel. Assumes a crew of 13 workers for a 90-hour period.
Cs/Sr waste	4.11	0.103	Assumes a crew of five workers for a 40-hour period.
Tc/UDS/hulls waste	1.45	0.145	Assumes a crew of five workers for a 20-hour period.
Ln/fission product waste	1.45	0.145	Assumes a crew of five workers for a 20-hour period.
GTCC-LLW AND MLLW	1.25	0.00624	Assumes a crew of five workers for a 20-hour period.
LLW AND MLLW	0.106	0.0105	Assumes a crew of five workers for a 60-hour period.
Am and Cm oxide product	0.770	0.320	Assumes a crew of five workers for a 60-hour period.
Uranium oxide product	0.769	0.320	Assumes a crew of five workers for a 60-hour period.
Uranium metal product	0.513	0.214	Assumes a crew of five workers for a 40-hour period.

4. Dose Scenarios Associated with Incident-Free Transportation	
Worker Populations	
Population	**Consistent with Yucca Mountain SEIS? (as provided in BMI 2007)**
An inspector working at a distance of 3.3 ft (1 m) from the rail or truck container for one hour per trailer or rail container.	Yes
A truck driver and passenger, expected to drive radioactive shipments for 1,000 hours per year and unload shipments for 1,000 hours per year.	Yes
Escort for truck shipments assumed to be present for entire shipment.	Yes

TABLE E.4-1—*Summary of Transportation Analysis Assumptions (continued)*

Worker Populations

Population	Consistent with Yucca Mountain SEIS? (as provided in BMI 2007)
Escort for rail shipments assumed to be present for entire shipment, including transfer periods at rail yards.	Rail escort in GNEP PEIS assumed to be 98 ft (30 m) from source. Yucca Mountain SEIS (DOE 2008f) assumes a distance of 90 ft (27 m).
General Population	
A person caught in traffic and located 4 ft (1.2 m) from shipping container for one hour.	Yes
A service station worker working at a distance of 66 ft (20m) from the shipping container for one hour.	No, Yucca Mountain SEIS assumes person at service station exposed for 49 minutes at a distance of 52 ft (16m). The GNEP analysis is consistent with Yucca Mountain FEIS analysis, which assumed a station worker at a distance of 66 ft (20 m).
Area residents near truck stop/service station, within 0.5 mile (0.8 km) from stop.	Yes
Resident living 98 ft (30 m) from the highway or rail line used to transport shipping container.	Yes
Resident 660 ft (200 m) from the rail stop where shipping container was sitting for 20 hours.	Yes

Frequency of Stops

Description of Stop	Consistent with Yucca Mountain SEIS? (as provided in BMI 2007)
Two-hour rail stops assumed to occur at 170-mile (277-km) intervals, or at a rate of 0.012 hr/mile (0.0072 hr/km).	Yes
Truck stops assumed to occur at a rate of 0.018 hr/mile (0.011 hr/km).	Yes

Vehicle Emission Impacts

Description	Consistent with Yucca Mountain SEIS?
Incident-free nonradiological vehicle emission fatalities were estimated using unit risk factors. These fatalities would result from exhaust and fugitive dust emissions from highway and rail traffic and are associated with 10-micrometer particles. The nonradiological unit risk factors were adopted from the transportation analysis conducted for the Yucca Mountain FEIS (DOE 2002i). The unit risk factors used in this analysis are 1.5×10^{-11} and 2.6×10^{-11} fatalities per kilometer per persons per square kilometer (km^2) for diesel truck and rail modes of transport respectively (Jason Technologies 2001).	Yes

5. Transportation Accident Risk Assessment Assumptions

Accident and Fatality Rates

Mode	Description	Consistent with Yucca Mountain SEIS?
Truck	Saricks and Tompkins 1999 rates with factors of 1.57 and 1.64 applied to account for underreporting of accident and fatality rates, respectively, as suggested by UMTRI 2003.	Yes
Rail and barge	Saricks and Tompkins 1999 rates	Yes

Conditional Probabilities and Release Fraction – Truck Scenario [i]

Materials/container type	Source Document
LWR, MOX, and thorium cycle spent fuels	Jason Technologies 2001
HWR spent fuel	BMI 2007
HTGR spent fuel	BMI 2007

TABLE E.4-1—*Summary of Transportation Analysis Assumptions (continued)*

Materials/container type	Source Document	
Fresh MOX fuel	NRC 2005c	
HLW canister	DOE 2004f	
9975 Class B waste drum	DOE 2004f	
Conditional Probabilities and Release Fraction – Rail Scenario [i]		
Materials/container type	**Source Document**	
LWR, MOX, and thorium cycle spent fuels	BMI 2007	
HWR spent fuel	BMI 2007	
HTGR spent fuel	BMI 2007	
HLW canister	DOE 2004f	
9975 Class B waste drum	DOE 2004f	
Severe Accident Transportation Accident Impacts [j]		
Parameter	**Value**	**Consistent with Yucca Mountain SEIS?**
Plume release height	33 ft (10 m)	Yes
Breathing rate	3.67×10^5 ft^3 ($1.04\times10^5 m^3$)	Yes
Short-term exposure time	2 hours	Yes
Long-term exposure time	1 year	Yes
Wind speed	2 mile/hr (0.89 m/s)	Yes
Atmospheric conditions	Pasquill Stability Class F	Yes
Urban population density	As provided in Table E.1.9.3-1	Yes
Rural population density	15.5 persons/mi^2 (6 persons/km^2)	Yes

[a] The container capacities for each material type was based upon volume, criticality, or thermal loading limits. Table E.2.2.2-1 provides the limiting factor for each material type and container. For the non-spent fuel material shipping, WGI 2008a and WGI 2008c were used as source documents.
[b] For this spent fuel type, it was assumed that DOE spent fuel canisters would be employed. The per-canister mass was calculated by dividing the total mass of the particular type by the total number of canisters, as provided in BMI 2007.
[c] For the purposes of this analysis, some waste streams were assumed to be packaged in HLW canisters that would not be classified as HLW. Waste classification and selection of specific transportation casks would be completed as the facility design and waste characteristics are further developed.
[d] It was assumed that five rail cars per shipment would be used for all materials, including spent fuels. In the Yucca Mountain SEIS, three rail cars per commercial spent fuel shipment and five rail cars per DOE spent fuel shipment were assumed. As with the Yucca Mountain SEIS assessment, spacer cars were added for spent fuel shipments. Spacer cars were also assumed for Cs/Sr waste shipments.
For non-spent fuel material and waste shipments, it was assumed that five rail cars per shipment would be used. Each rail car would have the same capacity of one truckload. This assumption is consistent with other DOE NEPA analyses including the Waste Management Programmatic EIS (DOE 1997) and the Idaho HLW and Facilities FEIS (DOE 2002e).
[e] Each DOE rail cask is assumed to hold nine DOE spent fuel canisters. Therefore, each rail cask is assumed to hold the equivalent of nine truck shipments. With five rail cars per shipment, each rail shipment is assumed to transport the equivalent of 45 truck shipments of this material.
[f] Inspection exposure analysis assumes that an inspector is located at a distance of 1 m from each truck trailer or rail car for a period of one hour.
[g] It was assumed that the loading impacts for all spent fuel types analyzed in this PEIS would be the same on a per-shipment basis
[h] It was assumed that inspection of rail shipments would occur at the origin and at the destination, for a total of two hours per rail car.
[i] The conditional probabilities and release fractions for the spent fuel types were provided by the Yucca Mountain SEIS and FEIS analyses. For the HLW and Class B drum containers, this information was taken from the WVDP Waste Management EIS.
[j] Severe transportation accidents, those with a frequency of approximately 1×10^{-7} per year, were analyzed using the RISKIND 2.0 computer code, consistent with the methodologies provided in BMI 2007.

E.5 REFERENCES

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10 CFR 71.47 NRC, "External Radiation Standards for All Packages," *Code of Federal Regulations*, Office of the Federal Register, National Archives and Records Administration, Washington, DC, Revised January 1, 2008.

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