APPENDIX D
TRANSPORTATION

D.1 INTRODUCTION

This appendix summarizes the methods and results of analysis for determining the environmental impacts of radioactive materials transportation on public highways and rail systems. The impacts are presented by alternative and include doses and health effects.

D.2 TRANSPORTATION REGULATIONS

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

- Protect persons and property from radiation emitted from packages during transportation, by specific limitations on the allowable radiation levels;
- 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); and
- Provide physical protection against theft and sabotage during transit.

The U.S. Department of Transportation 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 U.S. Nuclear Regulatory Commission (NRC), the Department of Transportation specifically regulates the carriers of radioactive materials and the conditions of transport such as routing, handling and storage, and vehicle and driver requirements. The Department of Transportation also regulates the labeling, classification, and marking of radioactive material packages.

The NRC regulates the packaging and transport of radioactive material for its licensees, which includes commercial shippers of radioactive materials. Under an agreement with the U.S. Department of Transportation, the NRC sets the standards for packages containing fissile materials and Type B packages. The NRC also establishes safeguards and security regulations to minimize the theft, diversion, or attack on certain shipments.

The U.S. Department of Energy (DOE), through its management directives, orders, and contractual agreements, ensures the protection of public health and safety by imposing standards on its transportation activities that are equivalent to those of the NRC and Department of Transportation. DOE has the authority, granted by a 1973 MOU between the Department of Transportation and the Atomic Energy Commission, 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 Title 10 of the Code of Federal Regulations (CFR) Part 71.

The U.S. Department of Transportation also has requirements that help reduce transportation impacts. For example, there are requirements for drivers, packaging, labeling, marking, and placarding. There are also requirements that specify the maximum dose rate associated with radioactive material shipments, which help reduce incident-free transportation doses.

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

Other agencies regulating the handling and transport of radioactive materials include the U.S. Postal Service, the Occupational Safety and Health Administration, and the U.S. Environmental Protection Agency.

Radioactive materials are transported in Excepted packages, Industrial packages, Type A packages, or Type B packages. The amount of radioactive material determines which package must be used. Excepted packages are used to transport materials with extremely low levels of radioactivity and must meet only general design requirements. Industrial packages are used to transport materials which present a limited hazard to the public and environment, such as contaminated equipment and radioactive waste solidified in materials such as concrete.

Type A packages are used to transport radioactive materials with higher concentrations of radioactivity such as low-level radioactive 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 degrees Celsius [70 degrees Fahrenheit]) and cold (-40 degrees Celsius [-40 degrees Fahrenheit]) temperatures
- Pressure changes of 3.6 pounds per square inch
- Normal vibration experienced during transportation
- Simulated rainfall of 5 centimeters (2 inches) per hour for 1 hour
- Free drop from 0.3 to 1 meter (1 to 4 feet), depending on the package weight
- Corner drop test
- Compression test
- Impact of a 6-kilogram (13.2-pound) steel cylinder with rounded ends dropped from 1 meter (3 feet) onto the most vulnerable surface of the cask.

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 both normal and accident conditions. In addition to the normal conditions outlined above, under accident conditions a Type B package must withstand:

- Free drop for 9 meters (30 feet) 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 500-kilogram (1,100-pound) mass from 9 meters (30 feet) onto the package resting on an unyielding surface
- Free drop from 1 meter (40 inches) onto the end of a 15-centimeter (6-inch) diameter vertical steel bar
- Exposure for not less than 30 minutes to temperatures of 800 degrees Celsius (1,475 degrees Fahrenheit)
- For all packages, immersion in at least 15 meters (50 feet) of water for 8 hours
- For some packages, immersion in at least 0.9 meter (3 feet) of water for 8 hours in an orientation most likely to result in leakage
- For some packages, immersion in at least 200 meters (660 feet) of water for 1 hour.

Compliance with these requirements is demonstrated by using a combination of simple calculational methods, computer modeling techniques, or full-scale or scale-model testing of casks.

D.3 TRANSPORTATION ROUTES

To assess incident-free and transportation accident impacts, route characteristics were determined for shipments from the West Valley Demonstration Project (WVDP) Site to Envirocare in Clive, Utah; the Hanford Site in Richland, Washington; the Idaho National Engineering and Environmental Laboratory; the Nevada Test Site (NTS) in Mercury, Nevada; the Oak Ridge National Laboratory in Tennessee; the Savannah River Site (SRS) in Aiken, South Carolina; and the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico. Representative highway and rail routes were analyzed using the routing computer code WebTRAGIS (Johnson and Michelhaugh 2000). The routes were calculated using current 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 data from the 2000 census. Table D-1 shows the truck and rail route distances and the population densities along the proposed routes.

The WebTRAGIS computer code predicts highway routes for transporting radioactive materials within the United States. The WebTRAGIS database is a computerized road atlas that currently describes approximately 386,000 kilometers (240,000 miles) 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 WebTRAGIS 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 U.S. Department of Transportation regulations (as specified in 49 CFR Part 397). The calculated routes conform to applicable guidelines and regulations and therefore represent routes that could be used. However, they may not be the actual routes used in the future. The code is updated periodically to reflect current road conditions, and it has been benchmarked against reported mileages and observations of commercial truck firms.

The WebTRAGIS computer code also is designed to simulate the routing of the U.S. rail system. The WebTRAGIS database consists of 94 separate subnetworks and represents various competing rail

Table D-1. Truck and Rail Route Distances and Population Densities

Origin	Destination	Distances (in kilometers)[a]			Population Densities (in person per square kilometer)[b]		
		Rural	Suburban	Urban	Rural	Suburban	Urban
Truck Routes							
WVDP	Envirocare	2,505.2	659.5	81.5	11.6	303.3	2,352.1
	SRS	856.3	583.1	35.4	17.7	309.0	2,197.5
	Hanford	3,222.1	792.0	82.2	11.2	294.5	2,309.8
	WIPP	2,482.8	1,225.0	77.1	15.3	292.1	2,115.7
	NTS/Yucca Mountain	3,055.0	756.7	115.9	11.0	308.9	2,468.1
	INEEL	2,642.9	702.3	70.3	11.8	295.2	2,325.3
	ORNL	716.4	517.1	25.2	19.3	291.5	2,110.5
SRS	WIPP	1,729.6	650.8	64.4	13.2	315.6	2,172.5
	NTS/Yucca Mountain	3,253.7	893.2	137.2	11.0	333.7	2,393.5
INEEL	WIPP	1,952.1	266.0	42.8	6.9	356.2	2,293.6
ORNL	WIPP	1,647.1	538.6	67.8	12.7	328.2	2,263.6
Hanford	WIPP	2,531.3	355.7	54.7	7.2	339.3	2,277.2
	NTS/Yucca Mountain	1,507.7	299.1	75.3	8.6	345.4	2,537.9
Rail Routes							
WVDP	Envirocare	2,778.9	502.5	176.1	8.2	423.4	2,482.9
	SRS	1,284.6	430.1	96.9	15.3	391.4	2,486.0
	Hanford	3,471.5	559.6	176.9	6.3	413.2	2,477.1
	WIPP	2,491.5	372.9	117.3	7.4	437.9	2,448.8
	NTS/Yucca Mountain (rail portion of route)	3,172.5	507.8	176.3	7.4	421.8	2,482.8
	NTS/Yucca Mountain (truck portion of route)	517.71	4.18	0.16	1.08	577.00	1,764.67
	INEEL	2,839.1	490.0	159.9	8.2	414.3	2,487.0
	ORNL	827.6	329.6	97.6	15.2	435.1	2,490.6

Table D-1. Truck and Rail Route Distances and Population Densities (cont)

Origin	Destination	Distances (in kilometers)[a]			Population Densities (in person per square kilometer)[b]		
		Rural	Suburban	Urban	Rural	Suburban	Urban
Rail Routes (cont)							
SRS	WIPP	2,512.2	421.6	78.7	9.9	415.7	2,188.4
	NTS/Yucca Mountain (rail portion of route)	3,479.1	550.9	125.5	7.4	418.6	2,280.7
	NTS/Yucca Mountain (truck portion of route)	517.71	4.18	0.16	1.08	577.00	1,764.67
INEEL	WIPP	2,169.7	162.2	42.5	3.6	421.8	2,292.5
ORNL	WIPP	2,458.6	360.4	63.8	8.0	388.7	2,241.2
Hanford	WIPP	2,986.1	214.0	57.2	3.7	428.8	2,262.3
	NTS/Yucca Mountain (rail portion of route)	1,597.5	124.3	38.0	4.7	400.2	2,370.1
	NTS/Yucca Mountain (truck portion of route)	517.71	4.18	0.16	1.08	577.00	1,764.67

Acronyms: WVDP = West Valley Demonstration Project; SRS= Savannah River Site; WIPP= Waste Isolation Pilot Plant; NTS = Nevada Test Site; INEEL = Idaho National Engineering and Environmental Laboratory; ORNL = Oak Ridge National Laboratory.

a. To convert kilometers to miles, multiply by 0.62137.

b. To convert people per square kilometer to people per square mile, multiply by 2.59.

companies in the United States. The database used by WebTRAGIS was originally based on Federal Railroad Administration data and reflected the U.S. railroad system in 1974. The database has since been expanded and modified over the past two decades. Standard assumptions in the WebTRAGIS computer code were applied to the routes analyzed for this EIS and simulate the selection process railroads used to direct shipments of radioactive material. Currently, there are no specific routing regulations for transporting radioactive material by rail. WebTRAGIS is updated periodically to reflect current track conditions, and it has been benchmarked against reported mileages and observations of commercial rail firms.

Because there is no rail access to the NTS, it was assumed that radioactive waste would be shipped to Nevada by rail to an intermodal transfer facility in Nevada and then shipped from the intermodal transfer facility to NTS by truck.

D.4 SHIPMENTS

Radioactive material shipments associated with the proposed alternatives are assumed to be transported by either truck or rail. At this time, insufficient data exist to determine what fraction of shipments would be shipped by either transport mode. Therefore, the transportation analysis assumed that radioactive materials would be shipped 100 percent by truck and 100 percent by rail to bound potential impacts.

Several types of containers were assumed to be used to transport the radioactive waste evaluated in this environmental impact statement (EIS). The types of containers, their volumes, and the numbers of containers in a shipment are listed in Table D-2. Table D-3 lists the waste volumes, numbers of containers, and numbers of shipments for each alternative evaluated in the EIS. In Tables D-2 and D-3, a shipment is defined as the amount of waste transported on a single truck or a single railcar. There may be multiple railcars per train, but the data used in the transportation analysis and the resulting transportation impacts are based on the number of railcars that are transported. For example, rail accident rates are based on the number of accidents per railcar-mile, not on the number of accidents per train-mile.

The waste volumes used in this EIS were based on current waste volumes and future projections. These volumes were then escalated by about 10 percent to account for the uncertainties in future waste projections, packaging efficiency, and the choice of shipping container. Using this process, contact-handled transuranic (CH-TRU) waste was escalated from 1,019 cubic meters (36,000 cubic feet) to 1,133 cubic meters (40,000 cubic feet); remote-handled transuranic (RH-TRU) waste was escalated from 227 cubic meters (8,000 cubic feet) to 255 cubic meters (9,000 cubic feet); and LLW was escalated from 12,743 cubic meters (450,000 cubic feet) to 14,158 cubic meters (500,000 cubic feet). Drum Cell waste was not escalated because actual container counts are known. The volume of Drum Cell waste was based on 19,877 71-gallon drums and an additional 500 71-gallon drums containing sodium-bearing waste. All Drum Cell waste and sodium-bearing waste was assumed to be Class C LLW. This yields a volume of 5,477 cubic meters (193,405 cubic feet), so the total volume of LLW analyzed was 19,635 cubic meters (693,405 cubic feet). The escalated volume includes 223 cubic meters (7,889 cubic feet) of mixed LLW.

D.5 INCIDENT-FREE TRANSPORTATION

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

Table D-2. Waste Types and Containers

Waste Type	Container	Container Volume (ft^3)[a]	Effective Volume (ft^3)	Number of Containers per Shipment
Class A LLW	B-25 box	90	81	14 (truck) 28 (rail)
Class A LLW	55-gallon drum	7.65	6.885	84 (truck) 168 (rail)
Class B LLW	HIC[b]	100	90	1 (truck) 4 (rail)
Class B LLW	55-gallon drum	7.65	6.885	84 (truck) 168 (rail)
Class C LLW	HIC[b]	100	90	1 (truck) 4 (rail)
Class C LLW	71-gallon drum[c]	9.5	9.5	24 (truck) 96 (rail)
Class C LLW	55-gallon drum[d]	7.65	6.885	10 (truck) 40 (rail)
CH-TRU	55-gallon drum[e]	7.65	6.885	42 (truck) 42 (rail)
RH-TRU	55-gallon drum[f]	7.65	6.885	10 (truck) 40 (rail)
MLLW	55-gallon drum	7.65	6.885	84 (truck) 168 (rail)
HLW	Canister	NA[g]	NA	1 (truck) 5 (rail)

Acronyms: LLW = low-level radioactive waste; HIC = high-integrity container; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; MLLW = mixed low-level waste; HLW = high-level radioactive waste.

a. To convert cubic feet to cubic meters, multiply by 0.028317.
b. High-integrity containers were assumed to be shipped in a Type B shipping container.
c. Solidified waste from the Drum Cell.
d. Class C drums were assumed to be shipped in a Type B shipping container holding 10 drums.
e. CH-TRU waste drums were assumed to be shipped in a Type B TRUPACT-II shipping container, which holds 14 drums. A truck or rail shipment was assumed to hold three TRUPACT-II shipping containers.
f. RH-TRU waste drums were assumed to be shipped in a Type B shipping container holding 10 drums.
g. NA = not applicable.

Radiological impacts were determined for crew workers and the general population during normal, incident-free transportation. For truck shipments, the crew were drivers of the shipment vehicles. For rail shipments, the crew were workers in close proximity to the shipping containers during inspection or classification of railcars. The general population was the individuals within 800 meters (2,625 feet) 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 computer code (Neuhauser et al. 2000).

Collective Dose Scenarios

Calculating the collective doses is based on developing unit risk factors. Unit risk factors provide an estimate of the impact from transporting one shipment of radioactive material over a unit distance of travel in a given population density zone. The unit risk factors may be combined with routing information such as the shipment distances in various population density zones to determine the risk for a

Table D-3. Waste Volumes, Containers, and Shipments By Alternative

Waste Type	No Action Alternative			Alternative A			Alternative B		
	Volume (ft^3)[a]	Number of Containers	Number of Shipments	Volume (ft^3)	Number of Containers	Number of Shipments	Volume (ft^3)	Number of Containers	Number of Shipments
Class A LLW (boxes)	97,649	1,206	87 (truck) 44 (rail)	351,586	4,341	311 (truck) 156 (rail)	351,586	4,341	311 (truck) 156 (rail)
Class A LLW (drums)	47,351	6,878	82 (truck) 41 (rail)	83,014	12,508	144 (truck) 72 (rail)	83,014	12,508	144 (truck) 72 (rail)
Class B LLW (HIC)	0	0	0	38,500	428	428 (truck) 107 (rail)	38,500	428	428 (truck) 107 (rail)
Class B LLW (drums)	0	0	0	194	29	1 (truck) 1 (rail)	194	29	1 (truck) 1 (rail)
Class C LLW (HIC)	0	0	0	12,618	141	141 (truck) 36 (rail)	12,618	141	141 (truck) 36 (rail)
Class C LLW (55-gallon drums)	0	0	0	6,198	901	91 (truck) 23 (rail)	6,198	901	91 (truck) 23 (rail)
Class C LLW (71-gallon drums)	0	0	0	193,405	20,377	850 (truck) 213 (rail)	193,405	20,377	850 (truck) 213 (rail)
CH-TRU	0	0	0	40,000	5,810	139 (truck) 139 (rail)	40,000	5,810	278 (truck)[b] 278 (rail)[b]
RH-TRU	0	0	0	9,000	1,308	131 (truck) 33 (rail)	9,000	1,308	262 (truck)[c] 66 (rail)[d]
MLLW	0	0	0	7,889	1,146	14 (truck) 7 (rail)	7,889	1,146	14 (truck) 7 (rail)
HLW		0	0		300	300 (truck) 60 (rail)		300	600 (truck)[e] 120 (rail)[f]
Total	145,000	8,084	169 (truck) 85 (rail)	742,404	46,839	2550 (truck) 847 (rail)	742,404	46,839	3,120 (truck)[g] 1,079 (rail)[h]

Acronyms: LLW = low-level radioactive waste; HIC = high-integrity container; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; MLLW = mixed low-level waste; HLW = high-level radioactive waste.

a. To convert cubic feet to cubic meters, multiply by 0.028317.
b. 139 CH-TRU shipments from WVDP to interim storage, 139 CH-TRU shipments from interim storage to disposal.
c. 131 RH-TRU shipments from WVDP to interim storage, 131 RH-TRU shipments from interim storage to disposal.
d. 33 RH-TRU shipments from WVDP to interim storage, 33 RH-TRU shipments from interim storage to disposal.
e. 300 HLW shipments from WVDP to interim storage, 300 HLW shipments from interim storage to disposal.
f. 60 HLW shipments from WVDP to interim storage, 60 HLW shipments from interim storage to disposal.
g. Includes 270 TRU waste, and 300 HLW, truck shipments from interim storage to disposal. Alternative B would load the same number of truck shipments (2,550) at WVDP for shipment offsite as Alternative A.
h. Includes 172 TRU waste, and 60 HLW, rail shipments from interim storage to disposal. Alternative B would load the same number of rail shipments (847) at WVDP for shipment offsite as Alternative A.

single shipment (a shipment risk factor) between a given origin and destination. Cashwell et al. (1986) contains a detailed explanation of the use of unit risk factors. Table D-4 contains the unit risk factors for truck and rail shipments.

Each waste type was assigned an external radiation dose rate representative of its constituents and shipping container. High-level waste (HLW), Class B LLW, and Class C LLW were assigned a dose rate of 14 millirem (mrem) per hour at 1 meter (3 feet) from their respective vehicles. Using the RADTRAN 5 computer code, this yields the regulatory maximum dose rate at 2 meters (7 feet) from the vehicle, which is 10 mrem per hour. RH-TRU waste was assigned a dose rate of 10 mrem per hour at 1 meter, and CH-TRU waste was assigned a dose rate of 4 mrem per hour at 1 meter (DOE 1997a). Class A LLW and mixed LLW were assigned a dose rate of 1 mrem per hour at 1 meter (DOE 1997b).

Incident-free nonradiological fatalities were also evaluated 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 factor for truck transport used in this analysis was 1.5×10^{-11} fatalities per kilometer per persons per square kilometer; for train transport, the nonradiological unit risk factor was 2.6×10^{-11} fatalities per kilometer per persons per square kilometer. Escorts for HLW shipments were assumed to be in automobiles, with a unit risk factor of 9.4×10^{-12} fatalities per kilometer per persons per square kilometer. These unit risk factors were estimated from the

Table D-4. Unit Risk Factors for Incident-Free Transportation

Receptor	Type of Zone	Rail	Truck
Public			
Off-link (rem per [persons per square kilometer] per kilometer)	Rural	3.90×10^{-8}	2.89×10^{-8}
	Suburban	6.24×10^{-8}	3.18×10^{-8}
	Urban	1.04×10^{-7}	3.18×10^{-8}
On-link (person-rem per kilometer per vehicle per hour)	Rural	1.21×10^{-7}	9.53×10^{-6}
	Suburban	1.55×10^{-6}	2.75×10^{-5}
	Urban	4.29×10^{-6}	9.88×10^{-5}
Residents near rest/refueling and walk-around stops (person-rem per [persons per square kilometer] per kilometer)	Rural	1.24×10^{-7}	5.50×10^{-9}
	Suburban	1.24×10^{-7}	5.50×10^{-9}
	Urban	1.24×10^{-7}	5.50×10^{-9}
Residents near rail classification stops (person-rem per [persons per square kilometer] per square kilometer)	Suburban	1.59×10^{-5}	NA[a]
Public including workers at rest/refueling stops (person-rem per kilometer)	Rural	NA	7.86×10^{-6}
	Suburban	NA	7.86×10^{-6}
	Urban	NA	7.86×10^{-6}
Workers			
Dose in moving vehicle (person-rem per kilometer)	Rural	NA	4.52×10^{-5}
	Suburban	NA	4.76×10^{-5}
	Urban	NA	4.76×10^{-5}
Classification stops at origin and destination (person-rem)	Suburban	0.0464	0.018
In-transit rail stops (person-rem per kilometer)	Rural	1.45×10^{-5}	NA
	Suburban	1.45×10^{-5}	NA
	Urban	1.45×10^{-5}	NA
Walk-around inspection (person-rem per kilometer)	Rural	NA	1.93×10^{-5}
	Suburban	NA	1.93×10^{-5}
	Urban	NA	1.93×10^{-5}

a. NA = not applicable.

data in Biwer and Butler (1999) and have been adjusted to account for more current diesel exhaust emission factors, a fleet average fugitive dust emission factor for roads, an age-adjusted mortality rate, and an average 10-micrometer particle risk factor. The distances used in the nonradiological analyses were doubled to reflect the round-trip distances, because these impacts could occur whether or not the shipments contain radioactive material.

Maximally Exposed Individual Exposure Scenarios

Maximum individual doses were calculated using the RISKIND computer code (Yuan et al. 1995). The maximum individual doses for the routine transport offsite were estimated for transportation workers and for members of the public. For rail shipments, the three scenarios for members of the public were:

- A railyard worker working at a distance of 10 meters (33 feet) from the shipping container for 2 hours,
- A resident living 30 meters (98 feet) from the rail line where the shipping container was being transported, and
- A resident living 200 meters (656 feet) from a rail stop where the shipping container was sitting for 20 hours.

For train shipments, the maximum exposed transportation worker was an inspector working 1 meter (3 feet) from the shipping container for 1 hour.

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

- A person caught in traffic and located 1 meter (3 feet) away from the surface of the shipping container for 30 minutes,
- A resident living 30 meters (98 feet) from the highway used to transport the shipping container, and
- A service station worker working at a distance of 20 meters (66 feet) from the shipping container for 1 hour.

The hypothetical maximum exposed individual doses were accumulated for all shipments over 1 year. For workers, it was assumed that they would be exposed to 23 percent of the shipments, based on working 2,000 hours per year. However, 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. Also, the maximum exposure rate for the truck driver was 2 mrem per hour (10 CFR 71.47(b)(4)).

D.6 TRANSPORTATION ACCIDENTS

The offsite transportation accident analysis considers the impacts of accidents during the transportation of waste 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, and the reader can obtain a detailed description from the referenced reports (NRC 1977; Fischer et al. 1987; Sprung et al. 2000). Accidents that could potentially breach the shipping container are represented by a spectrum of accident severities and radioactive release conditions. Historically, most transportation accidents involving radioactive materials have resulted in little or no release of radioactive material from the shipping container. Consequently, the analysis of accident risks takes into account a spectrum of accidents ranging from high-probability accidents of low severity to hypothetical high-severity accidents that have a correspondingly low probability of occurrence. This accident analysis calculates the probabilities and consequences from this spectrum of accidents.

To provide DOE and the public with a reasonable assessment of radioactive waste transportation accident impacts, two types of analyses were performed. First, an accident risk assessment was performed that takes into account the probabilities and consequences of a spectrum of potential accident severities using a methodology developed by the NRC (NRC 1977; Fischer et al. 1987; Sprung et al. 2000). For the spectrum of accidents considered in the analysis, accident consequences in terms of collective dose to the population within 80 kilometers (50 miles) were multiplied by the accident probabilities to yield collective dose risk using the RADTRAN 5 computer code (Neuhauser et al. 2000). Second, to represent the maximum reasonably foreseeable impacts to individuals and populations should an accident occur, radiological consequences were calculated for an accident of maximum credible severity in each population zone. An accident is considered credible if its probability of occurrence is greater than 1×10^{-7} per year (1 in 10 million per year). The accident consequence assessment for maximally exposed individuals and population groups was performed using the RISKIND computer code (Yuan et al. 1995).

The impacts for specific alternatives were calculated in units of dose (rem or person-rem). Impacts are further expressed as health risks in terms of estimated latent cancer fatalities in exposed populations. The health risk conversion factors used were derived from International Commission on Radiological Protection Publication 60 (ICRP 1991). The nonradiological impacts from transportation accidents (traffic fatalities) were also estimated.

D.6.1 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 and heavy combination trucks. For calculating the nonradiological impacts from transportation accidents, state-specific fatality rates were taken from data provided in Saricks and Tompkins (1999) for rail and heavy combination trucks.

D.6.2 Conditional Probabilities and Release Fractions

Accident severity categories for potential radioactive waste transportation accidents are described in three NRC reports: NUREG-0170 (NRC 1977) for radioactive waste in general; a report commonly referred to as the Modal Study (Fischer et al. 1987); and a reassessment of NUREG-0170 (Sprung et al. 2000). The latter two reports address only spent nuclear fuel. The Modal Study represents a refinement of the NUREG-0170 methodology, and the recent reassessment analysis, which compares more recent results to NUREG-0170, represents a further refinement of both studies. Even though none of the radioactive waste assumed to be shipped in this EIS is classified as spent nuclear fuel, many of the modeling techniques developed in Fischer et al. (1987) and Sprung et al. (2000) can be applied to the types of waste that would be shipped from the WVDP site. Thus, this section presents the results of analyses that extend the results presented in the reexamination of the transport risk to fuel types other than spent nuclear fuel.

Each of the risk analyses considers a spectrum of accidents of varying severity. Each first determines the conditional probability that the accident will be of a specified severity. Then, based on the accident environment associated with each severe accident, each models the behavior of the material being shipped and the response of the packaging. The models estimate the fraction of each species of radioactive material that might be released for each of the severe accidents being considered. Each of the NRC risk assessments has considered a different breakdown of the severe accident environment. The analyses presented in NUREG-0170 divides the accident environment into eight accident severity categories. Fischer et al. (1987) represented the severe accident environment as a matrix, with one dimension being midline temperature of the lead in the cask and the other dimension being cask deformation. The matrix contained a total of 20 cases. The most recent analysis (Sprung et al. 2000) also represented the severe accident environment as a matrix, with one dimension being the temperature of the radioactive material and the other being the velocity of impact onto an unyielding surface. The matrix contained 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 NUREG-0170 analyses did not specify the accident environment associated with each of the eight accident severity categories, whereas the later analyses both based their cases on a matrix of fire durations and mechanical impacts on the cask. 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.

Both the Modal Study and Sprung et al. (2000) distinguished among material types that are present in the waste form. In addition to release fractions for particulates, separate release fractions are specified for noble gases, cesium, ruthenium, and any crud that might be present on the external surfaces of the spent nuclear fuel cladding. Rather than carry between 19 and 21 accident severity cases through the analysis, a simple mathematical technique has been used to reduce the accident categories to 6 when estimating the transport accident risk.

The probability for the severity category was estimated using the following formula:

$$P_{Sci} = \sum_{j} P_{Cj}$$

where:

j represents the cases included in severity category i
P_{Cj} is the case j probability
P_{Sci} is the accident severity i probability

The probability weighting of the release fractions is calculated using the following formula:

$$RF_{Sci,m} = \frac{\sum_{j,m} RF_{Cj} * P_{Cj}}{P_{Sci}}$$

The use of the "i" and "j" subscripts in the above equation are the same as those used for the probability calculation. The additional "m" subscript has been added to represent the various material classes. The term "RF" is the fraction of the material in the cask released for a given material type. The two equations above are general and have been used to reduce the accident severity categories in NUREG-0170 from 8 to 6 and, in the case of the HLW and Class B and Class C shipping container analyses, from the 21 rail and 19 truck accident severity cases described by Sprung et al. (2000) to the 6 accident severity categories carried through this assessment. Use of these two equations reduces the level of detail carried into subsequent calculations without changing the overall risk estimate. Tables D-5 through D-10 show the six accident severity categories used to model the transportation accident risk for all the waste materials that may be shipped from the WVDP site.

Table D-5. Conditional Probabilities and Release Fractions for CH-TRU Waste Shipments

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.91	0	0.80	0
2	0.070	8.0×10^{-9}	0.18	2.0×10^{-8}
3	0.016	2.0×10^{-7}	0.018	7.0×10^{-7}
4	2.8×10^{-3}	8.0×10^{-5}	1.8×10^{-3}	8.0×10^{-5}
5	1.1×10^{-3}	2.0×10^{-4}	1.3×10^{-4}	2.0×10^{-4}
6	1.0×10^{-4}	2.0×10^{-4}	7.0×10^{-5}	2.0×10^{-4}

Source: DOE 1990.

Table D-6. Conditional Probabilities and Release Fractions for RH-TRU Waste 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}	8.8×10^{-5}
4	5.2×10^{-7}	2.6×10^{-5}	5.8×10^{-7}	5.3×10^{-4}
5	7.0×10^{-8}	6.2×10^{-5}	1.1×10^{-7}	1.3×10^{-4}
6	2.2×10^{-10}	6.7×10^{-5}	8.5×10^{-10}	2.9×10^{-4}

Source: DOE 1990.

Table D-7. Conditional Probabilities and Release Fractions for HLW 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}

Table D-8. Conditional Probabilities and Release Fractions for Class C LLW Drum Cell Waste Shipments

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.93	0	0.93	0
2	0.071	1.2×10^{-5}	0.069	1.2×10^{-5}
3	2.2×10^{-3}	3.1×10^{-5}	1.0×10^{-3}	3.1×10^{-5}
4	7.5×10^{-5}	8.8×10^{-6}	3.7×10^{-3}	3.3×10^{-5}
5	6.9×10^{-4}	5.0×10^{-5}	3.8×10^{-4}	5.9×10^{-5}
6	6.1×10^{-5}	5.7×10^{-5}	1.3×10^{-4}	7.5×10^{-5}

Table D-9. Conditional Probabilities and Release Fractions for Class A Drum and Box and Class B LLW Drum Waste Shipments

Severity Category	Truck		Rail	
	Conditional Probability	Release Fraction	Conditional Probability	Release Fraction
1	0.81	0	0.82	0
2	0.14	1.2×10^{-5}	0.14	1.2×10^{-5}
3	0.028	9.2×10^{-4}	0.019	9.1×10^{-4}
4	1.9×10^{-4}	5.0×10^{-4}	2.5×10^{-5}	5.0×10^{-4}
5	0.019	7.9×10^{-3}	0.015	7.7×10^{-3}
6	1.2×10^{-4}	0.38	9.7×10^{-4}	0.38

Table D-10. Conditional Probabilities and Release Fractions for Class B LLW High-Integrity Containers and Class C LLW Drum and High-Integrity 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}	8.8×10^{-5}
4	5.2×10^{-7}	2.6×10^{-5}	5.8×10^{-7}	5.3×10^{-4}
5	7.0×10^{-8}	6.2×10^{-5}	1.1×10^{-7}	1.3×10^{-4}
6	2.2×10^{-10}	6.7×10^{-5}	8.5×10^{-10}	2.9×10^{-4}

In developing the release fractions for the various waste types, the models developed in Sprung et al. (2000) combined separate responses of the waste form, its cladding, the response of the gases internal to the waste form and shipping container, and the shipping container. Waste form release fractions were estimated for the 21 rail and 19 truck cases. For shipping containers used for HLW and Class B and Class C waste, the response for the various accident environments represented by the 19 and 21 cases was assumed to be the same. To estimate the behavior of materials released from the clad to the internals of the packaging, Sprung et al. (2000) developed a deposition and gas expansion model to estimate the fraction of the material in the gas that might be released to the environment. To demonstrate how these models were adapted to one of the WVDP waste types, the modeling of the HLW canister behavior in the accident environment represented by the 21 rail and 19 truck severe accident cases will be described.

The first step was to make the assumption that because glass and ceramics are both brittle solids, both will have similar particulate release fractions when struck during a severe transportation accident. Because a melt temperature of 1,150 degrees Celsius (2,102 degrees Fahrenheit) is used to pour the HLW into the canister, no noble gases would be present in the waste form. Furthermore, any cesium or ruthenium present would be tightly bound to the boron and silicon in the HLW so they would behave as particulates instead of volatile species. Lastly, there would be no crud.

The second step was to replace the clad failure rate used in Sprung et al. (2000) for spent nuclear fuel with a canister failure model. Based on impact tests on simulated HLW canisters, it was estimated that 20 percent of the canisters would fail if they impacted a surface at between 48 and 97 kilometers (30 and 60 miles) per hour, 70 percent would fail if they impacted the surface at between 97 and 145 kilometers (60 and 90 miles) per hour, and all would fail if they impacted the surface at speeds in excess of 145 kilometers (90 miles) per hour. Furthermore, assuming the canister was sealed at room temperature, a stress analysis performed on the canister showed that it would not fail from pressure buildup when exposed to fires as high as 1,000 degrees Celsius (1,832 degrees Fahrenheit). This was the highest temperature considered in any of the cases modeled by Sprung et al. (2000).

The final two parts of the Sprung et al. (2000) analysis were deposition and gas displacement models. The deposition model estimated the fraction of the material released from the spent nuclear fuel clad that is deposited on the inside surfaces of the cask and clad and therefore not available for immediate release. The gas displacement model considers the pressure buildup inside the cask and the fraction of the gas that must be released to reduce the pressure inside the cask to atmospheric pressure. The model assumes the fraction of the radioactive material released from the cask is the same as the fraction of the internal gases that must be released from the cask to reduce the internal pressure in the cask to atmospheric pressure. In the modeling of the HLW releases, no changes were made to the gas displacement model. The source of the displacement was assumed to be the 1.9 atmosphere pressure internal to the canister during shipment. This pressure is based on the assumption that the canister was sealed at room temperature and operates at 300 degrees Celsius (572 degrees Fahrenheit) during shipment.

Once the 19 truck cases and the 21 rail cases have been modeled for the waste forms, the resultant conditional probabilities and release fractions were reduced to the 6 accident severity categories shown in Tables D-5 to D-10. While different assumptions were made, a similar process was performed to estimate the conditional probabilities and release fractions for the other waste forms. For the Class C drum cell waste shipments, the waste is contained in a grout matrix that is assumed to be have impact properties that are similar to those for the HLW and ceramic fuel. For the thermal behavior, the grout will basically turn back to powder, losing all its bound water, at 600º Celsius (1,112º Fahrenheit). A thermal model of a waste drum was used to estimate the fraction of the grout decomposed as a function of the fire duration. The conditional fire probabilities were the same as those used for the HLW, and the thermal release fraction for the decomposed grout used the release fraction for aggregate taken from DOE (1994). The results for this waste form are shown in Table D-8. For the waste in Type B containers, the HLW canister model was modified in two ways. First, the effect of the canister was removed, placing all of the release limits on the performance of the Type B packaging in the accident environment. This packaging was assumed to perform as the lead cask performed in Sprung et al. (2000). The other change was to use release fractions that are consistent with the type of waste being shipped, a surface-contaminated solid. These release fractions and conditional probabilities are shown in Tables D-6 and D-10. For the Class A waste shipped in drums and boxes, a crush model was used to estimate the fraction of the drums failed at various impact velocities, and the release fractions for combustible solids presented in DOE (1994) were thought to be most representative of these wastes. The release fractions and conditional probabilities for these waste forms are presented in Table D-9.

The RADTRAN 5 computer code was used to estimate accident unit risk factors (units of person-rem per kilometer per person per square kilometer) for each radionuclide in the various waste forms. An Access database was used to combine the unit risk factors with data on conditional probabilities, release fractions, accident rates, population densities, route distances, and radionuclide inventories to calculate the total accident dose risk for each alternative examined in the EIS. For a given alternative, the accident unit risk factors were first multiplied by the number of shipment kilometers through each population zone being traversed by the waste shipments and then by the population density associated with that population zone. By summing over all population zones traversed by the waste form and then over all waste forms being considered, the total accident dose risk for each of the alternatives has been obtained.

D.6.3 Shipment Inventories

The radionuclide inventories in Classes A, B, and C LLW were estimated from the five radionuclide mixes in Table 3-6 of Marschke (2001). The five radionuclide mixes were converted to radionuclide concentrations and scaled to arrive at the maximum radionuclide concentrations that were Class A, B, or

C waste. To determine which of the five mixes for each waste class had the greatest radiological hazard, the radionuclide concentration was divided by the A_2 value for each radionuclide from 10 CFR 71 and summed for each mix. The mix with the largest sum represents the mix with the largest radiological hazard; this mix was then used in the transportation risk assessment. The radionuclide concentrations were then converted to container inventories, which are presented in Table D-11. Radionuclide inventories for Drum Cell waste are presented in Table D-12.

Table D-11. Class A, B, and C Container Inventories[a]

Nuclide	Class A LLW		Class B LLW		Class C LLW	
	Drum[b] Inventory	Box Inventory	Drum Inventory	HIC[c] Inventory	Drum Inventory	HIC[c] Inventory
Hydrogen-3	1.56×10^{-6}	5.50×10^{-8}	6.76×10^{-8}	8.83×10^{-7}	6.76×10^{-7}	8.83×10^{-6}
Carbon-14	6.49×10^{-6}	7.23×10^{-8}	8.88×10^{-8}	1.16×10^{-6}	8.88×10^{-7}	1.16×10^{-5}
Iron-55	0	5.57×10^{-7}	6.84×10^{-7}	8.95×10^{-6}	6.84×10^{-6}	8.95×10^{-5}
Nickel-59	0	1.24×10^{-6}	1.52×10^{-6}	1.99×10^{-5}	1.52×10^{-5}	1.99×10^{-4}
Nickel-63	0	1.66×10^{-4}	2.04×10^{-4}	2.66×10^{-3}	2.04×10^{-3}	0.0266
Cobalt-60	0	1.16×10^{-8}	1.43×10^{-8}	1.87×10^{-7}	1.43×10^{-7}	1.87×10^{-6}
Strontium-90	7.02×10^{-4}	0.070	0.086	1.12	0.86	11.2
Technetium-99	2.49×10^{-7}	6.26×10^{-6}	7.68×10^{-6}	1.00×10^{-4}	7.68×10^{-5}	1.00×10^{-3}
Iodine-129	5.21×10^{-10}	0	0	0	0	0
Cesium-137	8.96×10^{-4}	0.798	0.98	12.8	9.80	128
Europium-154	5.48×10^{-6}	7.32×10^{-4}	8.99×10^{-4}	0.0118	8.99×10^{-3}	0.118
Actinium-227	5.85×10^{-10}	9.44×10^{-12}	1.16×10^{-11}	1.52×10^{-10}	1.16×10^{-10}	1.52×10^{-9}
Radium-228	3.43×10^{-11}	1.57×10^{-17}	1.93×10^{-17}	2.52×10^{-16}	1.93×10^{-16}	2.52×10^{-15}
Protactinium-231	2.21×10^{-9}	4.55×10^{-12}	5.58×10^{-12}	7.30×10^{-11}	5.58×10^{-11}	7.30×10^{-10}
Thorium-232	2.37×10^{-10}	9.25×10^{-17}	1.14×10^{-16}	1.49×10^{-15}	1.14×10^{-15}	1.49×10^{-14}
Uranium-232	4.09×10^{-6}	6.09×10^{-8}	7.48×10^{-8}	9.78×10^{-7}	7.48×10^{-7}	9.78×10^{-6}
Uranium-233	8.75×10^{-6}	1.08×10^{-7}	1.33×10^{-7}	1.74×10^{-6}	1.33×10^{-6}	1.74×10^{-5}
Uranium-234	4.34×10^{-7}	6.27×10^{-8}	7.70×10^{-8}	1.01×10^{-6}	7.70×10^{-7}	1.01×10^{-5}
Uranium-235	8.43×10^{-8}	1.40×10^{-9}	1.71×10^{-9}	2.24×10^{-8}	1.71×10^{-8}	2.24×10^{-7}
Uranium-238	9.49×10^{-7}	1.24×10^{-8}	1.52×10^{-8}	1.99×10^{-7}	1.52×10^{-7}	1.99×10^{-6}
Neptunium-237	3.71×10^{-9}	4.70×10^{-7}	5.77×10^{-7}	7.55×10^{-6}	5.77×10^{-6}	7.55×10^{-5}
Plutonium-238	2.79×10^{-4}	8.80×10^{-5}	1.08×10^{-4}	1.41×10^{-3}	1.08×10^{-3}	0.0141
Plutonium-239	3.92×10^{-4}	2.10×10^{-5}	2.58×10^{-5}	3.38×10^{-4}	2.58×10^{-4}	3.38×10^{-3}
Plutonium-240	2.78×10^{-4}	2.10×10^{-5}	2.58×10^{-5}	3.38×10^{-4}	2.58×10^{-4}	3.38×10^{-3}
Plutonium-241	0.011	7.62×10^{-4}	9.36×10^{-4}	0.0122	9.36×10^{-3}	0.122
Plutonium-242	2.27×10^{-7}	1.08×10^{-7}	1.33×10^{-7}	1.74×10^{-6}	1.33×10^{-6}	1.74×10^{-5}
Americium-241	2.87×10^{-5}	7.33×10^{-4}	9.00×10^{-4}	0.0118	9.00×10^{-3}	0.118
Americium-243	8.70×10^{-7}	8.61×10^{-6}	1.06×10^{-5}	1.38×10^{-4}	1.06×10^{-4}	1.38×10^{-3}
Curium-242	1.05×10^{-16}	5.10×10^{-6}	6.26×10^{-6}	8.19×10^{-5}	6.26×10^{-5}	8.19×10^{-4}
Curium-243	1.54×10^{-8}	7.97×10^{-5}	9.78×10^{-5}	1.28×10^{-3}	9.78×10^{-4}	0.0128
Curium-244	4.21×10^{-7}	7.97×10^{-5}	9.78×10^{-5}	1.28×10^{-3}	9.78×10^{-4}	0.0128

a. All inventories presented in curies.
b. Also used for mixed LLW shipment inventory.
c. HIC = high-integrity container

Table D-12. Drum Cell Waste Container Inventory

Nuclide	Drum Inventory (in curies)
Hydrogen-3	1.3×10^{-4}
Carbon-14	3.6×10^{-4}
Cobalt-60	6.0×10^{-8}
Nickel-63	3.5×10^{-5}
Strontium-90	0.027
Technetium-99	0.11
Antimony-125	1.0×10^{-4}
Iodine-129	1.8×10^{-5}
Cesium-137	0.021
Neptunium-237	4.3×10^{-5}
Plutonium-238	5.9×10^{-3}
Plutonium-239	1.2×10^{-3}
Plutonium-240	9.4×10^{-4}
Plutonium-241	0.067
Americium-241	1.4×10^{-3}
Plutonium-242	1.2×10^{-6}
Curium-242	8.6×10^{-12}

The radionuclide inventories for CH-TRU waste was taken from DOE (1997a) and are listed in Table D-13. The radionuclide inventory for RH-TRU waste was based on the radionuclide distribution for spent nuclear fuel, scaled to 2 curies of plutonium per 55-gallon drum, or 20 curies of plutonium per 10 drums, which is the limit for the shipping container. The radionuclide inventory is listed in Table D-13. The radionuclide inventory for HLW was taken from DOE (2002) and is listed in Table D-14.

Table D-13. TRU Waste Container Inventories[a]

Nuclide	CH-TRU Waste Drum Inventory	RH-TRU Waste Drum Inventory
Cobalt-60	4.6×10^{-5}	0
Strontium-90	7.1×10^{-4}	3.8
Cesium-137	7.1×10^{-4}	4.1
Thorium-228	0	1.2×10^{-3}
Uranium-232	0	1.2×10^{-3}
Uranium-233	0	0
Uranium-235	0	0
Uranium-238	0	0
Plutonium-238	71	0.26
Plutonium-239	1.1	0.073
Plutonium-240	0.30	0.055
Plutonium-241	14	1.6
Plutonium-242	4.9×10^{-5}	0
Americium-241	0.26	0.089
Americium-242	0	6.2×10^{-4}
Americium-242m	0	6.2×10^{-4}
Americium-243	0	3.9×10^{-3}
Curium-244	0	8.1×10^{-3}

a. All inventories presented in curies.

Table D-14. HLW Canister Inventory

Nuclide	Canister Inventory[a]
Actinium-227	0.046
Americium-241	200
Americium-242m	1.0
Americium-243	1.3
Carbon-14	0.53
Curium-242	0.84
Curium-243	0.28
Curium-244	11
Curium-245	3.4×10^{-3}
Curium-246	3.9×10^{-4}
Cesium-134	4.4×10^{-3}
Cesium-135	0.62
Cesium-137	16,000
Hydrogen-3	0.078
Iodine-129	8.1×10^{-4}
Niobium-93m	0.95
Neptunium-237	0.092
Protactinium-231	0.059
Palladium-107	0.042
Plutonium-238	27
Plutonium-239	6.4
Plutonium-240	4.7
Plutonium-241	95
Plutonium-242	6.4×10^{-3}
Radium-228	6.3×10^{-3}
Ruthenium-106	1.9×10^{-9}
Selenium-79	0.23
Samarium-151	270
Tin-126	0.4
Strontium-90	14,000
Technetium-99	6.5
Thorium-229	8.9×10^{-4}
Thorium-230	2.3×10^{-4}
Thorium-232	6.3×10^{-3}
Uranium-232	0.023
Uranium-233	0.037
Uranium-234	0.019
Uranium-235	3.9×10^{-4}
Uranium-236	1.1×10^{-3}
Uranium-238	3.3×10^{-3}
Zirconium-93	1.1
Nickel-59	0.41
Nickel-63	27
Cobalt-60	0.11

Source: DOE 2002.
a. All inventories presented in curies.

D.6.4 Atmospheric Conditions

Because it is impossible to predict the specific location of an offsite transportation accident, generic atmospheric conditions were selected for the risk and consequence assessments. For accident risk assessment, neutral weather conditions (Pasquill Stability Class D) were assumed. Neutral weather conditions are typified by moderate windspeeds, vertical mixing within the atmosphere, and good dispersion of atmospheric contaminants. Because neutral meteorological conditions compose the most frequently occurring atmospheric stability condition in the United States, these conditions are most likely to be present in the event of an accident involving a radioactive waste shipment. On the basis of observations from National Weather Service surface meteorological stations at 177 locations in the United States, on an annual average, neutral conditions (Pasquill Class C and D) occur 59 percent of the time, while stable (Pasquill Class E and F) and unstable (Pasquill Class A and B) conditions occur 33 percent and 8 percent of the time, respectively (CRWMS M&O 1999).

For the accident consequence assessment, doses were assessed under both neutral (Class D with 4.47 meters [14.67 feet] per second windspeed) and stable (Class F with 0.89 meter [2.92 feet] per second windspeed) atmospheric conditions. Stable weather conditions are typified by low windspeeds, very little vertical mixing within the atmosphere, and poor dispersion of atmospheric contaminants. Class F meteorology in combination with windspeeds of 0.89 meter per second generally occur no more than 12 percent of the time. Results calculated for neutral conditions represent the most likely consequences, and results for stable conditions represent a worst-case weather situation.

D.6.5 Population Density Zones

Three population density zones (rural, suburban, and urban) were used for the offsite population risk assessment. These zones respectively correspond to three mean population densities of 6, 719, and 3,861 persons per square kilometer. The actual population densities in the three zones were based on an aggregation of the twelve population density zones provided in the WebTRAGIS output and on data from the 2000 census.

D.6.6 Exposure Pathways

Radiological doses were calculated for an individual located near the scene of the accident and for populations within 80 kilometers (50 miles) of the accident. Rural, suburban, and urban population densities were assessed. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine) from the passing cloud, ingestion of contaminated crops, direct exposure (groundshine) from radioactivity deposited on the ground, and inhalation of resuspended radioactive particles from the ground.

D.6.7 Health Risk Conversion Factors

The following health risk conversion factors used to estimate latent cancer fatalities from radiological exposures were derived from International Commission on Radiological Protection Publication 60 (ICRP 1991): 5×10^{-4} and 4×10^{-4} latent cancer fatalities per person-rem for members of the public and workers, respectively. Although latent cancer fatalities are the predominant health risk associated with low-level radiation doses (that is, doses below the thresholds for acute effects), they are not the only potential detrimental health effect. Risks of other delayed health effects such as non-fatal cancers and hereditary effects should also be acknowledged. International Commission on Radiological Protection Publication 60 (ICRP 1991) has estimated that the total risk of detrimental health effects are 7.3×10^{-4} and 5.6×10^{-4} total detrimental health effects per person-rem for members of the public and workers, respectively.

D.7 RESULTS

D.7.1 Transportation Impacts

No Action Alternative. Table D-15 lists the transportation impacts under the No Action Alternative. If trucks were used to ship the radioactive waste, an estimated 0.030 to 0.037 fatality would occur. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type. Of that, about 60 percent would be from nonradiological traffic accidents and about 10 percent would be from nonradiological pollutants (diesel exhaust and fugitive dust).

If trains were used, an estimated 0.036 to 0.043 fatality would occur. About 70 percent would be from nonradiological traffic accidents and about 20 percent would be from nonradiological pollutants (diesel exhaust and fugitive dust).

Table D-15. Transportation Impacts Under the No Action Alternative

Waste Type	Destination	Incident-Free Public (person-rem)	Incident-Free Worker (person-rem)	Radiological Accident Dose Risk (person-rem)	Incident-Free Public (LCFs)	Incident-Free Worker (LCFs)	Radiological Accident Risk (LCFs)	Pollution Health Effects	Traffic Fatalities	Total Fatalities
Truck										
Class A	Envirocare	15	23	0.11	7.7×10^{-3}	9.2×10^{-3}	5.7×10^{-5}	2.1×10^{-3}	0.011	0.030
Class A	Hanford	19	27	0.12	9.3×10^{-3}	0.011	6.2×10^{-5}	2.3×10^{-3}	0.014	0.037
Class A	NTS	19	27	0.14	9.5×10^{-3}	0.011	7.1×10^{-5}	2.8×10^{-3}	0.013	0.036
Total Truck Fatalities: 0.030 – 0.037										
Rail										
Class A	Envirocare	27	24	0.45	0.014	9.7×10^{-3}	2.2×10^{-4}	3.0×10^{-3}	9.8×10^{-3}	0.036
Class A	Hanford	28	26	0.49	0.014	0.010	2.5×10^{-4}	3.1×10^{-3}	0.012	0.040
Class A	NTS	28	32	0.45	0.014	0.013	2.3×10^{-4}	3.0×10^{-3}	0.012	0.043
Total Rail Fatalities: 0.036 – 0.043										

Acronyms: LCFs = latent cancer fatalities; NTS = Nevada Test Site. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type.

Alternative A. Table D-16 lists the transportation impacts under Alternative A. If trucks were used to ship the radioactive waste, an estimated 0.69 to 0.72 fatality would occur. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type. Of that, about 30 percent would be from nonradiological traffic accidents and about 15 percent would be from nonradiological air pollutants.

If trains were used, an estimated 0.52 to 0.59 fatality would occur. Of that, about 30 percent would be from nonradiological traffic accidents and about 20 percent would be from nonradiological air pollutants.

Alternative B. Table D-17 lists the transportation impacts under Alternative B. If trucks were used to ship the radioactive waste, an estimated 0.76 to 0.87 fatality would occur. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type. Of that, about 35 percent would be from nonradiological traffic accidents and about 15 percent would be from nonradiological air pollutants.

If trains were used, an estimated 0.62 to 0.78 fatality would occur. Of that, about 30 percent would be from nonradiological traffic accidents and about 15 percent would be from nonradiological air pollutants.

Table D-16. Transportation Impacts Under Alternative A

Waste Type	Destination	Incident-Free		Radiological Accident Dose Risk (person-rem)	Incident-Free		Radiological Accident Risk (LCFs)	Pollution Health Effects	Traffic Fatalities	Total Fatalities
		Public (person-rem)	Worker (person-rem)		Public (LCFs)	Worker (LCFs)				
Truck										
Class A	Envirocare	41	62	0.23	0.021	0.025	1.1×10^{-4}	5.7×10^{-3}	0.030	0.081
	Hanford Site	50	74	0.24	0.025	0.029	1.2×10^{-4}	6.3×10^{-3}	0.038	0.098
	NTS	51	71	0.28	0.026	0.029	1.4×10^{-4}	7.6×10^{-3}	0.036	0.098
Class B	Hanford Site	47	130	1.4×10^{-3}	0.024	0.052	6.9×10^{-7}	5.9×10^{-3}	0.035	0.12
	NTS	48	120	1.6×10^{-3}	0.024	0.050	7.9×10^{-7}	7.1×10^{-3}	0.034	0.11
Class C	Hanford Site	140	400	9.1×10^{-4}	0.072	0.16	4.6×10^{-7}	0.018	0.11	0.36
	NTS	150	380	1.1×10^{-3}	0.074	0.15	5.4×10^{-7}	0.022	0.10	0.35
CH-TRU	WIPP	14	20	1.2	6.9×10^{-3}	8.0×10^{-3}	6.2×10^{-4}	2.3×10^{-3}	0.012	0.030
RH-TRU	WIPP	11	27	1.2×10^{-5}	5.4×10^{-3}	0.011	6.2×10^{-9}	2.2×10^{-3}	0.011	0.030
MLLW	Envirocare	1.3	1.9	0.017	6.4×10^{-4}	7.6×10^{-4}	8.7×10^{-6}	1.8×10^{-4}	9.2×10^{-4}	2.5×10^{-3}
	Hanford	1.5	2.3	0.019	7.7×10^{-4}	9.1×10^{-4}	9.4×10^{-6}	1.9×10^{-4}	1.2×10^{-3}	3.0×10^{-3}
	NTS	1.6	2.2	0.022	7.9×10^{-4}	8.8×10^{-4}	1.1×10^{-5}	2.3×10^{-4}	1.1×10^{-3}	3.0×10^{-3}
HLW	Repository	34	88	1.6×10^{-3}	0.017	0.035	8.1×10^{-7}	5.8×10^{-3}	0.024	0.082
Total Truck Fatalities: 0.69 – 0.72										
Rail										
Class A	Envirocare	73	65	0.88	0.037	0.026	4.4×10^{-4}	8.0×10^{-3}	0.026	0.097
	Hanford Site	74	70	0.97	0.037	0.028	4.8×10^{-4}	8.2×10^{-3}	0.034	0.11
	NTS	76	87	0.88	0.038	0.035	4.4×10^{-4}	8.1×10^{-3}	0.033	0.11
Class B	Hanford Site	70	66	5.6×10^{-3}	0.035	0.026	2.8×10^{-6}	3.9×10^{-3}	0.016	0.081
	NTS	71	90	5.1×10^{-3}	0.036	0.036	2.5×10^{-6}	3.8×10^{-3}	0.017	0.093
Class C	Hanford Site	220	200	2.0×10^{-3}	0.11	0.081	1.0×10^{-6}	0.012	0.049	0.25
	NTS	220	280	1.8×10^{-3}	0.11	0.11	9.1×10^{-7}	0.012	0.053	0.29
CH-TRU	WIPP	14	16	0.33	6.9×10^{-3}	6.5×10^{-3}	1.6×10^{-4}	3.4×10^{-3}	0.018	0.035
RH-TRU	WIPP	11	13	4.0×10^{-5}	5.5×10^{-3}	5.1×10^{-3}	2.0×10^{-8}	8.0×10^{-4}	4.2×10^{-3}	0.016
MLLW	Envirocare	2.2	2.0	0.068	1.1×10^{-3}	8.0×10^{-4}	3.4×10^{-5}	2.4×10^{-4}	8.1×10^{-4}	3.0×10^{-3}
	Hanford	2.3	2.2	0.075	1.1×10^{-3}	8.6×10^{-4}	3.8×10^{-5}	2.5×10^{-4}	1.0×10^{-3}	3.3×10^{-3}
	NTS	2.3	2.7	0.068	1.2×10^{-3}	1.1×10^{-3}	3.4×10^{-5}	2.5×10^{-4}	1.0×10^{-3}	3.5×10^{-3}
HLW	Repository	13	28	4.9×10^{-4}	6.3×10^{-3}	0.011	2.5×10^{-7}	4.2×10^{-3}	0.019	0.041
Total Rail Fatalities: 0.52 – 0.59										

Acronyms: LCFs = latent cancer fatalities; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; MLLW = mixed low-level waste; HLW = high-level radioactive waste; NTS = Nevada Test Site; WIPP = Waste Isolation Pilot Plant. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type.

Table D-17. Transportation Impacts Under Alternative B

Waste Type	Destination	Incident-Free Public (person-rem)	Incident-Free Worker (person-rem)	Radiological Accident Dose Risk (person-rem)	Incident-Free Public (LCFs)	Incident-Free Worker (LCFs)	Radiological Accident Risk (LCFs)	Pollution Health Effects	Traffic Fatalities	Total Fatalities
Truck										
Class A	Envirocare	41	62	0.23	0.021	0.025	1.1×10^{-4}	5.7×10^{-3}	0.030	0.081
	Hanford Site	50	74	0.24	0.025	0.029	1.2×10^{-4}	6.3×10^{-3}	0.038	0.098
	NTS	51	71	0.28	0.026	0.029	1.4×10^{-4}	7.6×10^{-3}	0.036	0.098
Class B	Hanford Site	47	130	1.4×10^{-3}	0.024	0.052	6.9×10^{-7}	5.9×10^{-3}	0.035	0.12
	NTS	48	120	1.6×10^{-3}	0.024	0.050	7.9×10^{-7}	7.1×10^{-3}	0.034	0.11
Class C	Hanford Site	140	400	9.1×10^{-4}	0.072	0.16	4.6×10^{-7}	0.018	0.11	0.36
	NTS	150	380	1.1×10^{-3}	0.074	0.15	5.4×10^{-7}	0.022	0.10	0.35
CH-TRU	SRS → WIPP	21	35	3.7	0.010	0.014	1.8×10^{-3}	3.8×10^{-3}	0.022	0.052
	INEEL → WIPP	29	50	2.9	0.014	0.020	1.5×10^{-3}	4.2×10^{-3}	0.025	0.065
	ORNL → WIPP	18	33	2.3	8.9×10^{-3}	0.013	1.1×10^{-3}	3.1×10^{-3}	0.017	0.043
	Hanford → WIPP	35	59	3.4	0.017	0.023	1.7×10^{-3}	4.9×10^{-3}	0.032	0.079
RH-TRU	SRS → WIPP	16	43	3.6×10^{-5}	8.1×10^{-3}	0.017	1.8×10^{-8}	3.6×10^{-3}	0.021	0.050
	INEEL → WIPP	23	65	3.4×10^{-5}	0.011	0.026	1.7×10^{-8}	4.0×10^{-3}	0.024	0.065
	ORNL → WIPP	14	40	2.2×10^{-5}	7.0×10^{-3}	0.016	1.1×10^{-8}	2.9×10^{-3}	0.016	0.042
	Hanford → WIPP	27	78	3.9×10^{-5}	0.014	0.031	1.9×10^{-8}	4.6×10^{-3}	0.030	0.080
MLLW	Envirocare	1.3	1.9	0.017	6.4×10^{-4}	7.6×10^{-4}	8.7×10^{-6}	1.8×10^{-4}	9.2×10^{-4}	2.5×10^{-3}
	Hanford Site	1.5	2.3	0.019	7.7×10^{-4}	9.1×10^{-4}	9.4×10^{-6}	1.9×10^{-4}	1.2×10^{-3}	3.0×10^{-3}
	NTS	1.6	2.2	0.022	7.9×10^{-4}	8.8×10^{-4}	1.1×10^{-5}	2.3×10^{-4}	1.1×10^{-3}	3.0×10^{-3}
HLW	SRS → Repository	53	130	4.3×10^{-3}	0.027	0.054	2.2×10^{-6}	9.6×10^{-3}	0.047	0.14
	Hanford → Repository	50	140	2.3×10^{-3}	0.025	0.055	1.2×10^{-6}	8.0×10^{-3}	0.037	0.12
										Total Truck Fatalities: 0.76 – 0.87

Table D-17. Transportation Impacts Under Alternative B (cont)

Waste Type	Destination	Incident-Free		Radiological Accident Dose Risk (person-rem)	Incident-Free		Radiological Accident Risk (LCFs)	Pollution Health Effects	Traffic Fatalities	Total Fatalities
Rail										
Class A	Envirocare	73	65	0.88	0.037	0.026	4.4×10^{-4}	8.0×10^{-3}	0.026	0.097
	Hanford Site	74	70	0.97	0.037	0.028	4.8×10^{-4}	8.2×10^{-3}	0.034	0.11
	NTS	76	87	0.88	0.038	0.035	4.4×10^{-4}	8.1×10^{-3}	0.033	0.11
Class B	Hanford Site	70	66	5.6×10^{-3}	0.035	0.026	2.8×10^{-6}	3.9×10^{-3}	0.016	0.081
	NTS	71	90	5.1×10^{-3}	0.036	0.036	2.5×10^{-6}	3.8×10^{-3}	0.017	0.093
Class C	Hanford Site	220	200	2.0×10^{-3}	0.11	0.081	1.0×10^{-6}	0.012	0.049	0.25
	NTS	220	280	1.8×10^{-3}	0.11	0.11	9.1×10^{-7}	0.012	0.053	0.29
CH-TRU	SRS → WIPP	35	45	1.4	0.018	0.018	6.9×10^{-4}	8.9×10^{-3}	0.057	0.10
	INEEL → WIPP	41	49	2.1	0.020	0.020	1.0×10^{-3}	0.010	0.038	0.089
	ORNL → WIPP	32	42	1.2	0.016	0.017	6.2×10^{-4}	8.0×10^{-3}	0.031	0.073
	Hanford → WIPP	47	53	2.5	0.023	0.021	1.3×10^{-3}	0.012	0.053	0.11
RH-TRU	SRS → WIPP	28	35	1.5×10^{-4}	0.014	0.014	7.3×10^{-8}	2.1×10^{-3}	0.013	0.044
	INEEL → WIPP	32	39	2.5×10^{-4}	0.016	0.015	1.2×10^{-7}	9.7×10^{-3}	0.036	0.077
	ORNL → WIPP	25	33	1.4×10^{-4}	0.013	0.013	6.8×10^{-8}	7.5×10^{-3}	0.030	0.063
	Hanford → WIPP	37	42	2.9×10^{-4}	0.018	0.017	1.5×10^{-7}	0.011	0.050	0.096
MLLW	Envirocare	2.2	2.0	0.068	1.1×10^{-3}	8.0×10^{-4}	3.4×10^{-5}	2.4×10^{-4}	8.1×10^{-4}	3.0×10^{-3}
	Hanford Site	2.3	2.2	0.075	1.1×10^{-3}	8.6×10^{-4}	3.8×10^{-5}	2.5×10^{-4}	1.0×10^{-3}	3.3×10^{-3}
	NTS	2.3	2.7	0.068	1.2×10^{-3}	1.1×10^{-3}	3.4×10^{-5}	2.5×10^{-4}	1.0×10^{-3}	3.5×10^{-3}
HLW	SRS → Repository	20	48	5.1×10^{-4}	9.9×10^{-3}	0.019	2.5×10^{-7}	6.1×10^{-3}	0.038	0.074
	Hanford → Repository	19	47	6.5×10^{-4}	9.4×10^{-3}	0.019	3.3×10^{-7}	5.3×10^{-3}	0.034	0.067
										Total Rail Fatalities: 0.62 – 0.78

Acronyms: LCFs = latent cancer fatalities; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; MLLW = mixed low-level waste; HLW = high-level radioactive waste; SRS = Savannah River Site; HF = Hanford Site; WIPP = Waste Isolation Pilot Plant; NTS = Nevada Test Site; INEEL = Idaho National Engineering and Environmental Laboratory; ORNL = Oak Ridge National Laboratory. The range of total fatalities is based on the minimum and maximum total fatalities for each waste type.

D.7.2 Incident-Free Radiation Doses to Maximally Exposed Individuals

No Action Alternative. Table D-18 lists the incident-free radiation doses for the maximally exposed individual scenarios under the No Action Alternative. If trucks were used to ship the waste, the maximally exposed worker would be a driver who would receive a radiation dose of about 250 mrem per year based on driving a truck carrying Class A LLW for about 700 hours per year. This is equivalent to a probability of a latent cancer fatality of about 1.0×10^{-4}.

Table D-18. Incident-Free Radiation Doses for the Maximally Exposed Individual Scenarios

Scenario	No Action Alternative	Alternative A	Alternative B
Truck			
Service station worker (member of the public)	0.10 mrem/yr (5.0×10^{-8} LCFs)	19 mrem/yr (9.5×10^{-6} LCFs)	19 mrem/yr (9.5×10^{-6} LCFs)
Individual in traffic jam (member of the public)	0.50 mrem (2.5×10^{-7} LCFs)	8.2 mrem (4.1×10^{-6} LCFs)	8.2 mrem (4.1×10^{-6} LCFs)
Nearby resident (member of the public)	1.1×10^{-4} mrem/yr (5.5×10^{-11} LCFs)	0.022 mrem/yr (1.1×10^{-8} LCFs)	0.022 mrem/yr (1.1×10^{-8} LCFs)
Driver (occupational)	250 mrem/yr (1.0×10^{-4} LCFs)	2,000 mrem/yr (8.0×10^{-4} LCFs)	2,000 mrem/yr (8.0×10^{-4} LCFs)
Rail			
Railyard worker (member of the public)	0.35 mrem/yr (1.8×10^{-7} LCFs)	35 mrem/yr (1.8×10^{-5} LCFs)	35 mrem/yr (1.8×10^{-5} LCFs)
Nearby resident (member of the public)	2.9×10^{-4} mrem/yr (1.5×10^{-10} LCFs)	0.055 mrem/yr (2.8×10^{-8} LCFs)	0.055 mrem/yr (2.8×10^{-8} LCFs)
Resident near rail stop (member of the public)	0.042 mrem/yr (2.1×10^{-8} LCFs)	8.0 mrem/yr (4.0×10^{-6} LCFs)	8.0 mrem/yr (4.0×10^{-6} LCFs)
Inspector (occupational)	1.9 mrem/yr (7.6×10^{-7} LCFs)	190 mrem/yr (7.6×10^{-5} LCFs)	190 mrem/yr (7.6×10^{-5} LCFs)

Under the No Action Alternative, the maximally exposed member of the public would be a person working at a service station who would receive a radiation dose of about 0.10 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 5.0×10^{-8}.

If trains were used to ship the waste, the maximally exposed worker would be an inspector. This worker would receive a radiation dose of about 1.9 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 7.6×10^{-7}. The maximally exposed member of the public was a railyard worker who was not directly involved with handling the railcars. This person would receive a radiation dose of about 0.35 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 1.8×10^{-7}.

Alternative A. Table D-18 lists the incident-free radiation doses for the maximally exposed individual scenarios under Alternative A. If trucks were used to ship the waste, the maximally exposed worker would be a driver who would receive a radiation dose of about 2,000 mrem per year based on driving a truck for 1,000 hours per year. This is equivalent to a probability of a latent cancer fatality of about 8.0×10^{-4}.

The maximally exposed member of the public would be a person working at a service station who would receive a radiation dose of about 19 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 9.5×10^{-6}.

If trains were used to ship the waste, the maximally exposed worker would be an inspector. This worker would receive a radiation dose of about 190 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 7.6×10^{-5}. The maximally exposed member of the public was a railyard worker who was not directly involved with handling the railcars. This person would receive a radiation dose of about 35 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 1.8×10^{-5}.

Alternative B. Table D-18 lists the incident-free radiation doses for the maximally exposed individual scenarios under Alternative B. If trucks were used to ship the waste, the maximally exposed worker would be a driver who would receive a radiation dose of about 2,000 mrem per year based on driving a truck for 1,000 hours per year. This is equivalent to a probability of a latent cancer fatality of about 8.0×10^{-4}.

The maximally exposed member of the public would be a person working at a service station who would receive a radiation dose of about 19 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 9.5×10^{-6}.

If trains were used to ship the waste, the maximally exposed worker would be an inspector. This worker would receive a radiation dose of about 190 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 7.6×10^{-5}. The maximally exposed member of the public was a railyard worker who was not directly involved with handling the railcars. This person would receive a radiation dose of about 35 mrem per year. This is equivalent to a probability of a latent cancer fatality of about 1.8×10^{-5}.

D.7.3 Impacts from Severe Transportation Accidents

In addition to analyzing the radiological and nonradiological risks of transporting radioactive waste from West Valley, DOE assessed the consequences of severe transportation accidents, known as maximum reasonably foreseeable transportation accidents. These severe accidents have a probability of about 1×10^{-7} per year. The consequences of these accidents were determined through the inhalation, groundshine, and immersion pathways.

The following assumptions were used to estimate the consequences of maximum reasonably foreseeable accidents:

- The release height of the plume is 10 meters (33 feet) for both fire- and impact-related accidents. Modeling the heat release rate of accident scenarios involving fire would result in lower consequences than modeling all events with a 10-meter release height.

- Breathing rate for individuals is assumed to be 10,400 cubic meters (13,600 cubic yards) per year (Neuhauser and Kanipe 2000).

- Short-term exposure to airborne contaminants is assumed to be 2 hours.

- Long-term exposure to contamination deposited on the ground is assumed to be 24 hours for the maximally exposed individual and 7 days for the population, with no interdiction or cleanup.

- The accident was assumed to occur in an urban area. The consequences for the maximum reasonably foreseeable accidents were estimated using 2000 census population density data from 0 to 80 kilometers (50 miles) for the 20 most populous urbanized areas in the country.

- Impacts were determined using low wind speeds and stable atmospheric conditions (a wind speed of 0.89 meters per second [2.9 feet per second] and Class F stability). The atmospheric concentrations estimated from these conditions would be exceeded only 5 percent of the time.

- The release fractions used in the analysis were for severity category 6 accidents (see Tables D-5 through D-10).

- The container inventories used in the analysis are listed in Tables D-11 through D-14. The number of containers that were assumed to be involved in the maximum reasonably foreseeable accident are listed in Table D-19. In several cases, multiple Type B shipping containers could be transported in a single shipment (see Table D-2). Because it is unlikely that a severe accident would breach multiple Type B shipping containers, a single Type B shipping container was assumed to be breached in the maximum reasonably foreseeable accident.

Table D-19. Number of Containers Involved in the Maximum Reasonably Foreseeable Transportation Accident

Case	Mode	Container Type	Number of Containers Involved
Class A LLW drums	Rail	55-gallon drum	168 55-gallon drums
Class A LLW boxes	Rail	B-25 box	28 B-25 boxes
Class A LLW drums	Truck	55-gallon drum	84 55-gallon drums
Class A LLW boxes	Truck	B-25 box	14 B-25 boxes
Class B LLW drums	Rail	55-gallon drum	168 55-gallon drums
Class B LLW HIC	Rail	High-integrity container	1 high-integrity container in one Type B shipping container
Class B LLW drums	Truck	55-gallon drum	84 55-gallon drums
Class B LLW HIC	Truck	High-integrity container	1 high-integrity container in one Type B shipping container
Class C LLW drums	Rail	55-gallon drum	10 55-gallon drums in one Type B shipping container
Class C LLW HIC	Rail	High-integrity container	1 high-integrity container in one Type B shipping container
Class C LLW drums	Truck	55-gallon drum	10 55-gallon drums in one Type B shipping container
Class C LLW HIC	Truck	High-integrity container	1 high-integrity container in one Type B shipping container
Drum Cell Drums	Rail	71-gallon drum	24 71-gallon drums
Drum Cell Drums	Truck	71-gallon drum	96 71-gallon drums
CH-TRU	Rail	55-gallon drum	14 55-gallon drums in one TRUPACT-II Type B shipping container
CH-TRU	Truck	55-gallon drum	14 55-gallon drums in one TRUPACT-II Type B shipping container
RH-TRU	Rail	55-gallon drum	10 55-gallon drums in one Type B shipping container
RH-TRU	Truck	55-gallon drum	10 55-gallon drums in one Type B shipping container
HLW	Rail	Canister	1 canister in one Type B truck shipping container
HLW	Truck	Canister	5 canisters in one Type B rail shipping container

Acronyms: LLW = low-level waste; HIC = high-integrity container; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; HLW = high-level radioactive waste

No Action Alternative. The maximally exposed individual would receive a radiation dose of 4.6 rem from the maximum reasonably foreseeable transportation accident involving a truck shipment of Class A LLW (Table D-20). This is equivalent to a risk of a latent cancer fatality of about 2.3×10^{-3}. The probability of this accident is about 5×10^{-7} per year. The population would receive a collective radiation dose of about 1,300 person-rem from this truck accident involving Class A LLW. This could result in about 1 latent cancer fatality.

For the maximum reasonably foreseeable transportation rail accident involving Class A LLW, the maximally exposed individual would receive a radiation dose of about 9.2 rem (Table D-20). This is equivalent to a risk of a latent cancer fatality of about 4.6×10^{-3}. The probability of this accident is about 2×10^{-6} per year. The population would receive a collective radiation dose of about 2,600 person-rem from this rail accident involving Class A LLW. This could result in about 1 latent cancer fatality.

Table D-20. Consequences of Severe Transportation Accidents[a]

Case	Mode	Severity Category	Individual Dose (rem)	Individual LCF	Population Dose (person-rem)	Population LCF
Class A LLW drums	Rail	6	9.2	4.6×10^{-3}	2,600	1.3
Class A LLW boxes	Rail	6	2.1	1.0×10^{-3}	580	0.29
Class A LLW drums	Truck	6	4.6	2.3×10^{-3}	1,300	0.65
Class A LLW boxes	Truck	6	1.0	5.2×10^{-4}	290	0.15
Class B LLW drums	Rail	6	15	7.7×10^{-3}	4,300	2.2
Class B LLW HIC	Rail	6	7.3×10^{-6}	3.6×10^{-9}	8.1×10^{-3}	4.1×10^{-6}
Class B LLW drums	Truck	6	7.7	3.8×10^{-3}	2,200	1.1
Class B LLW HIC	Truck	6	1.3×10^{-5}	6.5×10^{-9}	5.0×10^{-3}	2.5×10^{-6}
Class C LLW drums	Rail	6	5.6×10^{-5}	2.8×10^{-8}	0.062	3.1×10^{-5}
Class C LLW HIC	Rail	6	7.3×10^{-5}	3.6×10^{-8}	0.081	4.1×10^{-5}
Class C LLW drums	Truck	6	9.8×10^{-5}	4.9×10^{-8}	0.038	1.9×10^{-5}
Class C LLW HIC	Truck	6	1.3×10^{-4}	6.5×10^{-8}	0.050	2.5×10^{-5}
Drum Cell Drums	Rail	6	6.6×10^{-3}	3.3×10^{-6}	2.7	1.3×10^{-3}
Drum Cell Drums	Truck	6	2.0×10^{-5}	9.9×10^{-9}	0.51	2.6×10^{-4}
CH-TRU	Rail	6	25	0.012	6,600	3.3
CH-TRU	Truck	6	25	0.012	6,600	3.3
RH-TRU	Rail	6	0.14	7.1×10^{-5}	32	0.016
RH-TRU	Truck	6	0.14	7.1×10^{-5}	32	0.016
HLW	Rail	6	1.7×10^{-3}	8.7×10^{-7}	44	0.022
HLW	Truck	6	2.3×10^{-3}	1.1×10^{-6}	0.96	4.8×10^{-4}

Acronyms: LCF = latent cancer fatality; LLW = low-level waste; HIC = high-integrity container; CH-TRU = contact-handled transuranic waste; RH-TRU = remote-handled transuranic waste; HLW = high-level radioactive waste
a. Impacts are for stable meteorological conditions. Population impacts are in an urban area.

Alternative A. For waste shipped under Alternative A, the maximum reasonably foreseeable truck or rail transportation accident with the highest consequences would involve CH-TRU waste. Because one transuranic package transporter (TRUPACT-II) shipping container was assumed to be involved in either the truck or rail accident, the consequences for the truck or rail accident are the same. However, the probabilities of the truck and rail accidents are slightly different. The probability of the truck accident was 6×10^{-7} per year; for rail, the probability of the accident was 1×10^{-7} per year. The maximally exposed individual would receive a radiation dose of about 25 rem from this accident (Table D-20), which is equivalent to a latent cancer fatality risk of 0.012. The population would receive a collective radiation dose of approximately 6,600 person-rem from this accident. This could result in about 3 latent cancer fatalities.

Alternative B. For waste shipped under Alternative B, the maximum reasonably foreseeable truck or rail transportation accident with the highest consequences would involve CH-TRU waste. Because one TRUPACT-II shipping container was assumed to be involved in either the truck or rail accident, the consequences for the truck or rail accident are the same. However, the probabilities of the truck and rail accidents are slightly different. The probability of the truck accident was 1×10^{-6} per year; for rail, the probability of the accident was 5×10^{-7} per year. The maximally exposed individual would receive a radiation dose of about 25 rem from this accident (Table D-20), which is equivalent to a latent cancer fatality risk of 0.012. The population would receive a collective radiation dose of approximately 6,600 person-rem from this accident. This could result in about 3 latent cancer fatalities.

Using the screening procedure in *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE 2000), the sum of fractions of the biota concentration guides for the Class A LLW accidents and the CH-TRU accident were less than 1. Therefore, the radioactive releases from the Class A LLW accidents and the CH-TRU accident are not likely to cause persistent, measurable deleterious changes in populations or communities of terrestrial or aquatic plants or animals.

D.8 REFERENCES

Biwer, B.M., and J.P. Butler, 1999. "Vehicle Emission Unit Risk Factors for Transportation Risk Assessments." *Risk Analysis,* 19(6):1157-1171.

Cashwell et al. (J.W. Cashwell, K.S. Neuhauser, P.C. Reardon, and G.W. McNair), 1986. *Transportation Impacts of the Commercial Radioactive Waste Management Program*. Albuquerque, NM: Sandia National Laboratories; Report No. SAND85-2715.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor), 1999. *Environmental Baseline File for National Transportation*. Las Vegas, Nevada: CRWMS M&O; Report No. B00000000-01717-5705-00116 REV 01.

DOE (U.S. Department of Energy), 1990. *Final Supplement Environmental Impact Statement for the Waste Isolation Pilot Plant*. DOE/EIS-0026-FS, Washington, DC, January.

DOE (U.S. Department of Energy), 1994. *DOE Handbook, Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*. Report No. DOE-HDBK-3010-94. Washington, DC: U.S. Department of Energy.

DOE (U.S. Department of Energy), 1997a. *Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement*. DOE/EIS-0026-S-2, Washington, DC, September.

DOE (U.S. Department of Energy), 1997b. *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste* (Volumes 1 through 5), DOE/EIS-0200-F, Washington, DC, May.

DOE (U.S. Department of Energy), 2000. *Draft Technical Standard, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*, Washington, DC.

DOE (U.S. Department of Energy), 2002. *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*, DOE/EIS-0250, Washington, DC, February.

Fischer et al. (L.E. Fischer, C.K. Chou, M.A. Gerhard, C.Y. Kimura, R.W. Martin, R.W. Mensing, M. E. Mount, and M.C. Witte), 1987. *Shipping Container Response to Severe Highway and Railway Accident Conditions*. Washington, DC: U.S. Nuclear Regulatory Commission; Report No. NUREG/CR-4829.

ICRP (International Commission on Radiological Protection), 1991. *1990 Recommendations of the International Commission on Radiological Protection*. ICRP Publication 60. Elmsford, NY: Pergamon Press, Annals of the ICRP; 21(1-3).

Johnson, P.E., and R.D. Michelhaugh, 2000. *Transportation Routing Analysis Geographic Information System (WebTRAGIS) User's Manual*. Oak Ridge, TN: Oak Ridge National Laboratory; Report No. ORNL/TM-2000/86.

Marschke, S.F., 2001. *West Valley Demonstration Project Decontamination and Waste Management Environmental Impact Statement Engineering Report*, Revision 1. Prepared by Stephen F. Marschke, Gemini Consulting Company, for West Valley Nuclear Services Company: West Valley, NY. August.

Neuhauser, K.S., and F.L. Kanipe, 2000. *RADTRAN 5, User Guide*. Albuquerque, NM: Sandia National Laboratories; Report No. SAND2000-1257.

Neuhauser et al. (K.S. Neuhauser, F.L. Kanipe, and R.F. Weiner), 2000. *RADTRAN 5 Technical Manual*. Albuquerque, NM: Sandia National Laboratories; Report No. SAND2000-1256.

NRC (U.S. Nuclear Regulatory Commission), 1977. *Final Environmental Impact Statement on the Transportation of Radioactive Materials By Air and Other Modes*. Washington, DC: U.S. Nuclear Regulatory Commission; Report No. NUREG-0170.

Saricks, C.L., and M.M. Tompkins, 1999. *State-Level Accident Rates of Surface Freight Transportation: A Reexamination*. Argonne, Illinois: Argonne National Laboratory; Report No. ANL/ESD/TM-150.

Sprung et al. (J.L. Sprung, D.J. Ammerman, N.L. Breivik, R.J. Dukart, F.L. Kanipe, J.A. Koski, G.S. Mills, K.S. Neuhauser, H.D. Radloff, R.F. Weiner, and H.R. Yoshimura), 2000. *Reexamination of Spent Fuel Shipment Risk Estimates*. Washington, DC: U.S. Nuclear Regulatory Commission; Report No. NUREG/CR-6672.

Yuan et al. (Y.C. Yuan, S.Y. Chen, B. Biwer, and D.J. LePoire), 1995. *RISKIND- A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel*, Argonne National Laboratory; Report No. ANL/EAD-1, Argonne, IL.

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