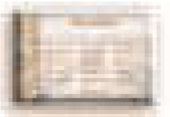

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Appendix J

Transportation

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APPENDIX J. TRANSPORTATION

This appendix provides additional information for readers who wish to gain a better understanding of the methods and analyses the U.S. Department of Energy (DOE) used to determine the human health impacts of transportation for the Proposed Action and Inventory Modules 1 and 2 discussed in this environmental impact statement (EIS). The materials included in Module 1 are the 70,000 metric tons of heavy metal (MTHM) for the Proposed Action and additional quantities of spent nuclear fuel and high-level radioactive waste that DOE could dispose of in the repository as part of a reasonably foreseeable future action. The materials included in Module 2 include the materials in Module 1 and other highly radioactive materials. Appendix A describes materials included in Modules 1 and 2. This appendix also provides the information DOE used to estimate traffic fatalities that would be associated with the long-term maintenance of storage facilities at 72 commercial sites and 5 DOE sites.

The appendix describes the key data and assumptions DOE used in the analyses and the analysis tools and methods the Department used to estimate impacts of loading operations at 72 commercial and 5 DOE sites; incident-free transportation by highway, rail and barge; intermodal transfer; and transportation accidents. The references listed at the end of this appendix contain additional information.

This appendix presents information on analyses of the impacts of national transportation and on analyses of the impacts that could occur in Nevada. Section J.1 presents information on the analysis of occupational and public health and safety impacts for the transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository. Section J.2 presents information on the analysis of rail and intermodal transportation options. Section J.3 presents information on the analysis of transportation in Nevada. Section J.4 presents a summary assessment of the Nevada transportation implementing alternatives.

J.1 Methods Used To Estimate Potential Impacts of National Transportation

This section provides information on the methods and data DOE used to estimate impacts from shipping spent nuclear fuel and high-level radioactive waste from 72 commercial sites and 5 DOE sites throughout the United States to the Yucca Mountain Repository.

MOSTLY LEGAL-WEIGHT TRUCK AND MOSTLY RAIL SCENARIOS

The Department does not anticipate that either the mostly legal-weight truck or the mostly rail scenario represents the actual mix of truck or rail transportation modes it would use. Nonetheless, DOE used these scenarios as a basis for the analysis of potential impacts to ensure the analysis addressed the range of possible transportation impacts. Thus, the estimated numbers of shipments for the mostly legal-weight truck and mostly rail scenarios represent only the two extremes in the possible mix of transportation modes. Therefore, the analysis provides estimates that cover the range of potential impacts to human health and safety and to the environment for the transportation modes DOE could use for the Proposed Action.

J.1.1 ANALYSIS APPROACH AND METHODS

Three types of impacts could occur to the public and workers from transportation activities associated with the Proposed Action. These would be a result of the transportation of spent nuclear fuel and high-level radioactive waste and of the personnel, equipment, materials, and supplies needed to construct, operate and monitor, and close the proposed Yucca Mountain Repository. The first type, radiological impacts, would be measured by radiological dose to populations and individuals and the resulting estimated number of latent cancer fatalities that would be caused by radiation from shipments of spent nuclear fuel and high-level radioactive waste from the 77 sites under normal and accident transport conditions. The second and third types would be nonradiological impacts—fatalities caused by vehicle emissions and fatalities caused by vehicle accidents. The analysis also estimated impacts due to the characteristics of hazardous cargoes from accidents during the transportation of nonradioactive hazardous materials to support repository construction, operation and monitoring, and closure. For perspective, about 10 fatalities resulting from hazardous material occur each year during the transportation of more than 300 million shipments of hazardous materials in the United States (DOT 1998a, Table 1). Therefore, DOE expects that the risks from exposure to hazardous materials that could be released during shipments to and from the repository sites would be very small (see Section J.1.4.2.4). The analysis evaluated the impacts of traffic accidents and vehicle emissions arising from these shipments.

The analysis used a step-wise process to estimate impacts to the public and workers. The process used the best available information from various sources and computer programs and associated data to accomplish the steps. Figures J-1 and J-2 show the steps followed in using data and computer programs. DOE has determined that the computer programs identified in the figure are suitable, and provide results in the appropriate measures, for the analysis of impacts performed for this EIS.

The CALVIN computer program (TRW 1998, all) is used to estimate the numbers of shipments of spent nuclear fuel from commercial sites. This program uses information on spent nuclear fuel stored at each site and an assumed scenario for picking up the spent fuel from each site. The program also uses information on the capacity of shipping casks that could be used.

The HIGHWAY computer program (Johnson et al. 1993a, all) is a routing tool used to select existing highway routes that would satisfy Department of Transportation route selection regulations and that DOE could use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The INTERLINE computer program (Johnson et al. 1993b, all) is a routing tool used to select existing rail routes that railroads would be likely to use to ship spent nuclear fuel and high-level radioactive waste from the 77 sites to the repository.

The RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) is used to estimate the radiological dose risks to populations and transportation workers of incident-free transportation and to the general population from accident scenarios. For the analysis of incident-free transportation risks, the code uses scenarios for persons who would share transportation routes with shipments—called *onlink populations*, persons who live along the route of travel—*offlink populations*, and persons exposed at stops. For accident risks, the code evaluates the range of possible accident scenarios from high probability and low consequence to low probability and high consequence.

The RISKIND computer program (Yuan et al. 1995, all) is used to estimate radiological doses to maximally exposed individuals for incident-free transportation and to populations and maximally exposed individuals for accident scenarios. To estimate incident-free doses to maximally exposed individuals, RISKIND uses geometry to calculate the dose rate at specified locations that would arise from a source of radiation. RISKIND is also used to calculate the radiation dose to a population and hypothetical maximally exposed individuals from releases of radioactive materials that are postulated to occur in maximum reasonably foreseeable accident scenarios.

The following sections describe these programs in detail.

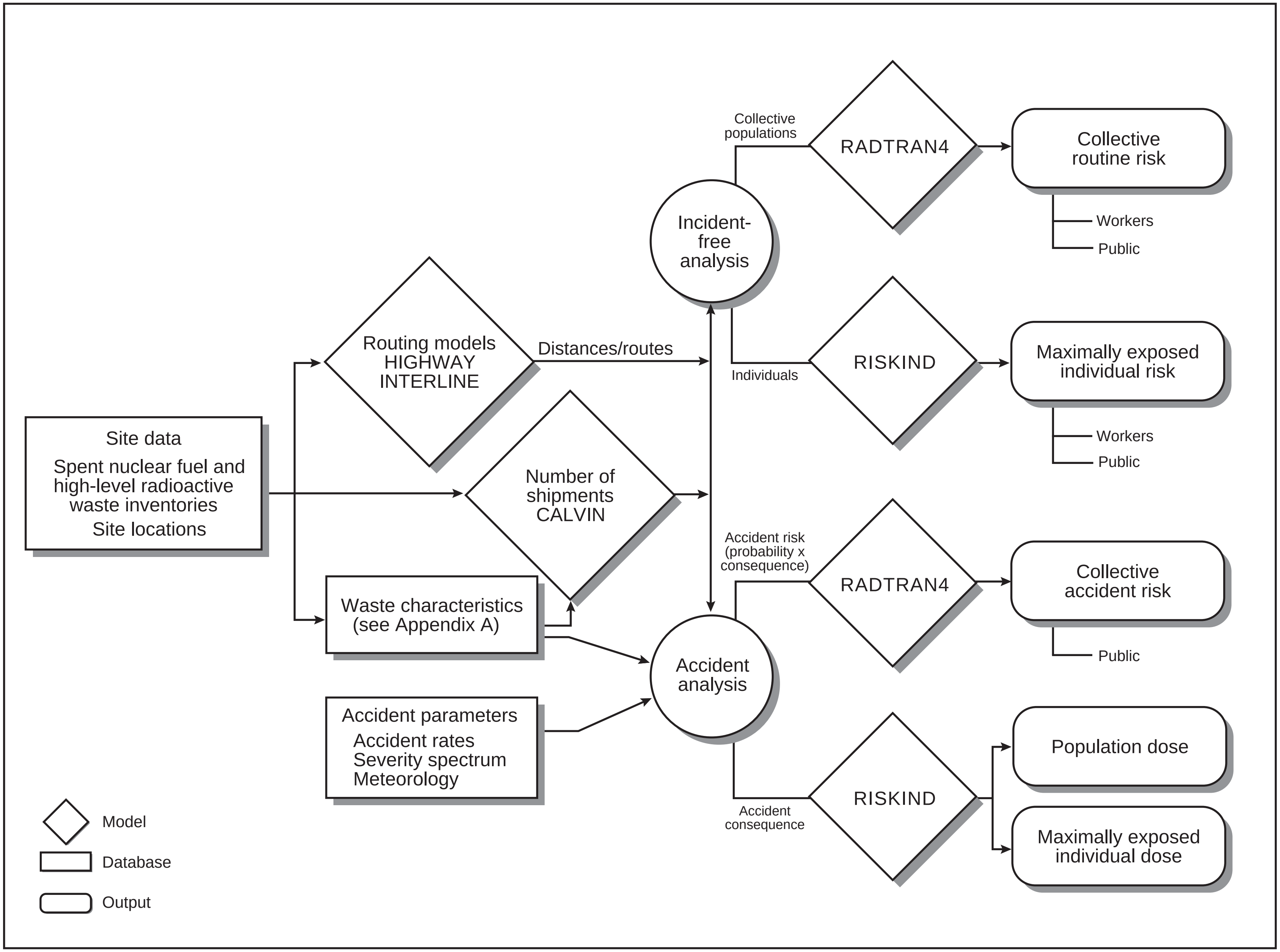


Figure J-1. Methods and approach for analyzing transportation radiological health risk.

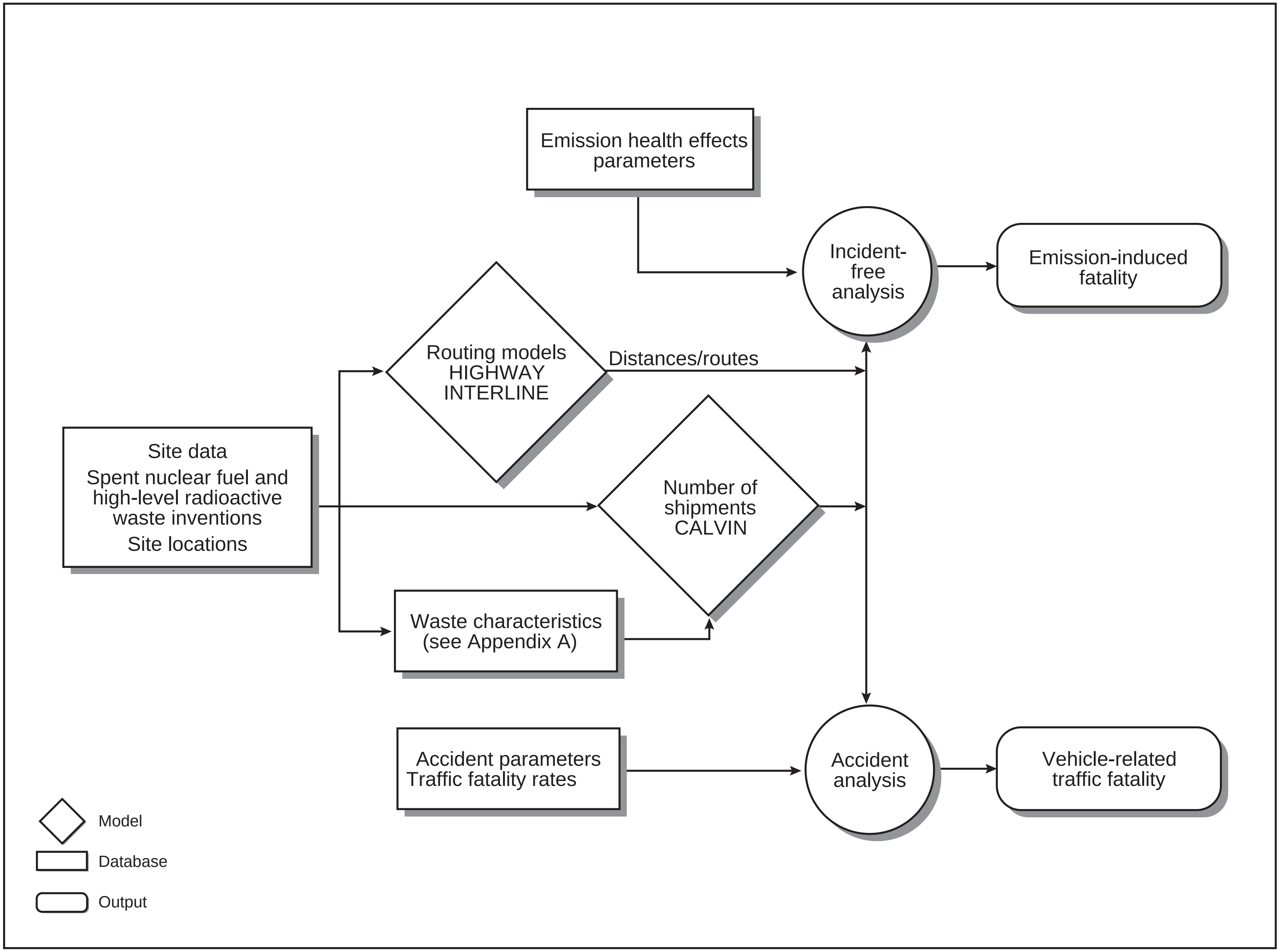


Figure J-2. Methods and approach for analyzing transportation nonradiological health risk.

DOSE RISK

Dose risk is a measure of radiological impacts to populations – public or workers – from the potential for exposure to radioactive materials. Thus, a potential of 1 chance in 1,000 of a population receiving a collective dose of 1 rem (1 person-rem) from an accident would result in a dose risk of 0.001 person-rem (0.001 is the product of 1 person-rem and the quotient of 1 over 1,000). Dose risk is often expressed in units of latent cancer fatalities.

The use of dose risk to measure radiological impacts allows a comparison of alternatives with differing characteristics in terms of radiological consequences that could result and the likelihood that the consequences would actually occur.

J.1.1.1 CALVIN

The Civilian Radioactive Waste Management System Analysis and Logistics Visually Interactive (CALVIN) model (TRW 1998, all) was developed to be a planning tool to estimate the logistic and cost impacts of various operational assumptions for accepting radioactive wastes. CALVIN is used in transportation modeling to determine the number of shipments of commercial spent nuclear fuel from each reactor site. The parameters that the CALVIN model used to determine commercial spent nuclear fuel movement include the shipping cask specifications including heat limits, $k_{infinity}$ (measure of criticality) limits for the contents of the casks, capacity (assemblies or canisters/cask), burnup/enrichment curves, and cooling time for the fuel being shipped.

The source data used by CALVIN for commercial spent nuclear fuel projections include the RW-859 historic data collected by the Energy Information Administration, and the corresponding projection produced based on current industry trends for commercial fuel (see Appendix A). This EIS used CALVIN to estimate commercial spent nuclear fuel shipment numbers based on the cask capacity (see Section J.1.2) and the shipping cask handling capabilities at each site. For the mostly rail national transportation scenario, CALVIN assumed that shipments would use the largest cask a site would be capable of handling. In some cases, CALVIN estimated that the characteristics of the spent nuclear fuel that would be picked up at a site would exceed the capabilities of the largest cask if the cask was fully loaded. In such cases, to provide a realistic estimate of the number of shipments that would be made, the program derated (reduced the capacity of) the casks. The reduction in capacity was sufficient to accommodate the characteristics of the spent nuclear fuel the program estimated for pickup at the site.

J.1.1.2 HIGHWAY

The HIGHWAY computer program (Johnson et al. 1993a, all) was used to select highway routes for the analysis of impacts presented in this EIS. HIGHWAY calculates routes by minimizing the total impedance between the origin and the destination. The impedance is determined by distance and driving time along a particular segment of highway. Using Rand McNally route data and rules that apply to carriers of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101), HIGHWAY selected highway routes for legal-weight truck shipments from each commercial and DOE site to the Yucca Mountain site. In addition, DOE used this program to estimate the populations within 800 meters (0.5 mile) of the routes it selected. These population densities were used in calculating incident-free radiological risks to the public along the routes.

One of the features of the HIGHWAY model is its ability to estimate routes for the transport of Highway Route-Controlled Quantities of Radioactive Materials. The Department of Transportation has established a set of routing regulations for the transport of these materials (49 CFR 397.101). Routes following these regulations are frequently called HM-164 routes. The regulations require the transportation of these shipments on preferred highways, which include:

- Interstate highways
- An Interstate System bypass or beltway around a city
- State-designated preferred routes

State routing agencies can designate preferred routes as an alternative to, or in addition to, one or more Interstate highways. In making this determination, the state must consider the safety of the alternative preferred route in relation to the Interstate route it is replacing, and must register all such designated preferred routes with the Department of Transportation.

Frequently, the origins and destinations of Highway Route-Controlled Quantities of Radioactive Materials are not near Interstate highways. In general, the Department of Transportation routing regulations require the use of the shortest route between the pickup location to the nearest preferred route entry location and the shortest route to the destination from the nearest preferred route exit location. In general, HM-164 routes tend to be somewhat longer than other routes; however, the increased safety associated with Interstate highway travel is the primary purpose of the routing regulations.

Because many factors can influence the time in transit over a preferred route, a carrier of Highway Route-Controlled Quantities of Radioactive Materials must select a route for each shipment. Seasonal weather conditions, highway repair or construction, highways that are closed because of natural events (for example, a landslide in North Carolina closed Interstate 40 near the border with Tennessee from June until November 1997), and other events (for example, the 1996 Olympic Games in Atlanta, Georgia) are all factors that must be considered in selecting preferred route segments to reduce time in transit. For this analysis, the highway routes were selected by the HIGHWAY program using an assumption of normal travel and without consideration for factors such as seasons of the year or road construction delays. Although these shipments could use other routes, DOE considers the impacts determined in the analyses to be representative of other possible routings that would also comply with Department of Transportation regulations. Specific route mileages for truck transportation are presented in Section J.1.2.1.1.

In selecting existing routes for use in the analysis, the HIGHWAY program determined the length of travel in each type of population zone—rural, suburban, and urban. The program characterized rural, suburban, and urban population areas according to the following breakdown: rural population densities range from 0 to 54 persons per square kilometer (0 to 140 persons per square mile); the suburban range is 55 to 1,300 persons per square kilometer (140 to 3,300 persons per square mile); and urban is all population densities greater than 1,300 persons per square kilometer (3,300 persons per square mile). The population densities along a route used by the HIGHWAY program are derived from 1990 data from the Bureau of the Census.

J.1.1.3 INTERLINE

Shipments of radioactive materials by rail are not subject to route restrictions imposed by regulations. For general freight rail service, DOE anticipates that railroads would route shipments of spent nuclear fuel and high-level radioactive waste to provide expeditious travel and the minimum practical number of interchanges between railroads. The selection of a route determines the potentially exposed population along the route as well as the expected frequency of transportation-related accidents. The analysis used the INTERLINE computer program (Johnson et al. 1993b, all) to project the railroad routes that DOE would use to ship spent nuclear fuel and high-level radioactive waste from the sites to the Yucca Mountain site. Specific routes were projected for each originating generator with the exception of 9 that do not have capability to handle or load a rail transportation cask (see Section J.1.2.1.1, Table J-6).

INTERLINE computes rail routes based on rules that simulate historic routing practices of U.S. railroads. The INTERLINE data base consists of 94 separate subnetworks and represents various competing rail companies in the United States. The data base, which was originally based on data from the Federal Railroad Administration and reflected the U.S. railroad system in 1974, has been expanded and modified extensively over the past two decades. The program is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations of commercial rail firms. The program also provides an estimate of the population within 800 meters (0.5 mile) of the routes it selected. This population estimate was used to calculate incident-free radiological risk to the public along the routes selected for analysis.

In general, rail routes are calculated by minimizing the value of a factor called *impedance* between the origin and the destination. The impedance is determined by considering trip distance along a route, the mainline classification of the rail lines that would be used, and the number of interchanges that would occur between different railroad companies involved. In general, impedance determined by the INTERLINE program:

- Decreases as the distance traveled decreases
- Is reduced by use of mainline track that has the highest traffic volume (see below)
- Is reduced for shipments that involve the fewest number of railroad companies

Thus, routes that are the most direct, that use high-traffic volume mainline track, and that involve only one railroad company would have the lowest impedance. The most important of these characteristics from a routing standpoint is the *mainline classification*, which is the measure of traffic volume on a particular link. The mainline classifications used in the INTERLINE routing model are as follows:

- A – mainline – more than 20 million gross ton miles per year
- B – mainline – between 5 and 20 million gross ton miles per year
- A – branch line – between 1 and 5 million gross ton miles per year
- B – branch line – less than 1 million gross ton miles per year

The INTERLINE routing algorithm is designed to route a shipment preferentially on the rail lines having the highest traffic volume. Frequently traveled routes are preferred because they are generally well maintained because the railroad depends on these lines for a major portion of its revenue. In addition, routing along the high-traffic lines usually replicates railroad operational practices.

The population densities along a route were derived from 1990 data from the Bureau of the Census, as described above for the HIGHWAY computer program.

DOE anticipates that routing of rail shipments in dedicated (special) train service, if used, would be similar to routing of general freight shipments for the same origin and destination pairs. However, because cask cars would not be switched between trains at classification yards, dedicated train service would be likely to result in less time in transit.

J.1.1.4 RADTRAN4

The RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) was used for the routine and accident cargo-related risk assessment to estimate the radiological impacts to collective populations. RADTRAN4 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by a variety of modes, including truck, rail, air, ship, and barge. The code has been used extensively for transportation risk assessment since it was issued in the late 1970s and has been reviewed and updated periodically. In 1995, a validation of the RADTRAN4 code demonstrated that it yielded acceptable results (Maheras and Pippen 1995, page iii). In the context of the validation analysis, *acceptable results* means that the difference between the estimates generated by the RADTRAN4 code and hand calculations were small, that is, less than 5 percent (Maheras and Pippen 1995, page 3-1).

The RADTRAN4 calculations for routine (or incident-free) dose are based on expressing the dose rate as a function of distance from a point source. Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of the exposure, vehicular speed, stopping time, traffic density, and route characteristics such as population density. In calculating population doses from incident-free transportation, the RADTRAN4 program used population density data provided by the HIGHWAY and INTERLINE computer programs. These data are based on the 1990 Census.

In addition to routine doses, RADTRAN4 was used to estimate dose risk from a spectrum of accident scenarios. The spectrum of accident scenarios encompass the range of possible accidents, including low-probability accident scenarios that have high consequences, and high-probability accident scenarios that have low consequences (fender benders). The RADTRAN4 calculation of collective accident risk for populations along routes employed models that quantified the range of potential accident severities and the responses of the shipping casks to the accident scenarios. The spectrum of accident severity was divided into categories. Each category of severity received a conditional probability of occurrence; that is, the probability that an accident will be of a particular severity if an accident occurs — the more severe the accident, the more remote the chance of such an accident. A release fraction, which is the fraction of the material in a shipping cask that could be released in an accident, is assigned to each accident scenario severity category on the basis of the physical and chemical form of the material being transported. The model also takes into account the mode of transportation, the state-specific accident rates, and population densities for rural suburban, and urban population zones through which shipments would pass to estimate accident risks for this analysis. The RADTRAN4 program used actual population densities within 800 meters (0.5 mile) of transportation routes based on 1990 census data as the basis for estimating populations within 80 kilometers (50 miles).

For accident scenarios involving the release of radioactive material, RADTRAN4 assumes that the material is dispersed in the environment as described by a Gaussian dispersion model. The dispersion analysis assumes that meteorological conditions are national averages for wind speed and atmospheric stability. For the risk assessment, the analysis used these meteorological conditions and assumed an instantaneous ground-level release and a small diameter source cloud (Neuhauser and Kanipe 1993, page 5-6). The calculation of the collective population dose following the release and the dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud
- External exposure to contaminated ground
- Internal exposure from inhalation of airborne contaminants
- Internal exposure from ingestion of contaminated food

For the ingestion pathway, the analysis used state-specific food transfer factors (TRW 1999a, page 35), which relate the amount of radioactive material ingested to the amount deposited on the ground, as input to the RADTRAN4 code. Radiation doses from the ingestion or inhalation of radionuclides were calculated by using standard dose conversion factors from Federal Guidance Reports No. 11 and 12 (TRW 1999a, page 36).

J.1.1.5 RISKIND

The RISKIND computer program (Yuan et al. 1995, all) was used as a complement to the RADTRAN4 calculations to estimate scenario-specific doses to maximally exposed individuals for both routine operations and accident conditions and to estimate population impacts for the assessment of accident scenario consequences. The RISKIND code was originally developed for the DOE Office of Civilian Radioactive Waste Management specifically to analyze radiological consequences to individuals and population subgroups from the transportation of spent nuclear fuel and is used now to analyze the transport of other radioactive materials, as well as spent nuclear fuel.

The RISKIND external dose model considers direct external exposure and exposure from radiation scattered from the ground and air. RISKIND was used to calculate the dose as a function of distance from a shipment on the basis of the dimensions of the shipment (millirem per hour for stationary exposures and millirem per event for moving shipments). The code approximates the shipment as a cylindrical volume source, and the calculated dose includes contributions from secondary radiation scatter from buildup (scattering by material contents), cloudshine (scattering by air), and groundshine (scattering by the ground). Credit for potential shielding between the shipment and the receptor was not considered.

The RISKIND code was also used to provide a scenario-specific assessment of radiological consequences of severe transportation-related accidents. Whereas the RADTRAN4 risk assessment considers the entire range of accident severities and their related probabilities, the RISKIND consequence assessment focuses on accident scenarios that result in the largest releases of radioactive material to the environment. The consequence assessment was intended to provide an estimate of the potential impacts posed by a severe, but highly unlikely, transportation-related accident scenario.

The dose to each maximally exposed individual considered was calculated with RISKIND for an exposure scenario defined by a given distance, duration, and frequency of exposure specific to that receptor. The distances and durations were similar to those given in previous transportation risk assessments. The scenarios were not meant to be exhaustive but were selected to provide a range of potential exposure situations.

J.1.2 NUMBER AND ROUTING OF SHIPMENTS

This section discusses the number of shipments and routing information used to analyze potential impacts that would result from preparation for and conduct of transportation operations to ship spent nuclear fuel and high-level radioactive waste to the Yucca Mountain site. Table J-1 summarizes the estimated numbers of shipments for the various inventory and national shipment scenario combinations.

J.1.2.1 Number of Shipments

DOE used two analysis scenarios—mostly legal-weight truck and mostly train (rail)—as bases for estimating the number of shipments of spent nuclear fuel and high-level radioactive waste from 72 commercial and 5 DOE sites. The number of shipments for the scenarios was used in analyzing transportation impacts for the Proposed Action and Inventory Modules 1 and 2. DOE selected the scenarios because, more than 10 years before the projected start of operations at the repository, it cannot accurately predict the actual mix of rail and legal-weight truck transportation that would occur from the 77 sites to the repository. Therefore, the selected scenarios enable the analysis to bound (or bracket) the ranges of legal-weight truck and rail shipments that could occur.

Table J-1. Summary of estimated numbers of shipments for the various inventory and national transportation analysis scenario combinations.

	Mostly truck		Mostly rail	
	Truck	Rail	Truck	Rail
Proposed Action				
Commercial spent nuclear fuel	37,738	0	2,601	8,386
High-level radioactive waste	8,315	0	0	1,663
Spent nuclear fuel	3,470	300	0	766
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Proposed Action totals	**49,523**	**300**	**2,601**	**10,815**
Module 1[a]				
Commercial spent nuclear fuel	66,850	0	3,701	13,906
High-level radioactive waste	22,280	0	0	4,456
Spent nuclear fuel	3,721	300	0	797
Greater-Than-Class-C waste	0	0	0	0
Special-Performance-Assessment-Required waste	0	0	0	0
Module 1 totals	**92,851**	**300**	**3,701**	**19,159**
Module 2[a]				
Commercial spent nuclear fuel	66,850	0	3,701	13,906
High-level radioactive waste	22,280	0	0	4,456
Spent nuclear fuel	3,721	300	0	797
Greater-Than-Class-C waste	1,096	0	0	282
Special-Performance-Assessment-Required waste	2,010	0	0	404
Module 2 totals	**95,957**	**300**	**3,701**	**19,845**

a. The number of shipments for Module 1 includes all shipments of spent nuclear fuel and high-level radioactive waste included in the Proposed Action and shipments of additional spent nuclear fuel and high-level radioactive waste as described in Appendix A. The number of shipments for Module 2 includes all the shipments in Module 1 and additional shipments of highly radioactive materials described in Appendix A.

The analysis estimated the number of shipments from commercial sites where spent nuclear fuel would be loaded and shipped and from DOE sites where spent nuclear fuel, naval spent nuclear fuel, and high-level radioactive waste would be loaded and shipped.

For the mostly legal-weight truck scenario, with one exception, shipments were assumed to use legal-weight trucks. Overweight, overdimensional trucks weighing between about 36,300 and 52,300 kilograms (80,000 and 115,000 pounds) but otherwise similar to legal-weight trucks could be used for some spent nuclear fuel and high-level radioactive waste (for example, spent nuclear fuel from the South Texas reactors). The exception that gives the scenario its name—mostly legal-weight truck—was for shipments of naval spent nuclear fuel. Under this scenario, naval spent nuclear fuel would have to be shipped by rail because of the size and weight of the shipping container (cask) that would be used.

For the mostly rail scenario, the analysis assumed that all sites would ship by rail, with the exception of those with physical limitations that would make rail shipment impractical. The exception would be for shipments by legal-weight trucks from 9 commercial sites that do not have the capability to load rail casks. The analysis assumed that 19 commercial sites that do not have direct rail service but that could handle large casks would ship by barge or heavy-haul truck to nearby railheads with intermodal capability.

For commercial spent nuclear fuel, the CALVIN code was used to compute the number of shipments. The number of shipments of DOE spent nuclear fuel and high-level radioactive waste was estimated based on the data in Appendix A and information provided by the DOE sites. The numbers of shipments were estimated based on the characteristics of the materials shipped, mode interface capability (for example, the lift capacity of the cask-handling crane) of each shipping facility, and the modal-mix case analyzed. Table J-2 summarizes the basis for the national and Nevada transportation impact analysis.

Table J-2. Analysis basis—national and Nevada transportation scenarios.[a,b]

Material	Mostly legal-weight truck scenario national and Nevada	National mostly rail scenario	
		Nevada rail scenario	Nevada heavy-haul truck scenario
Casks			
Commercial SNF	Truck casks – about 1.8 MTHM per cask	Rail casks – 6 to 12 MTHM per cask for shipments from 63 sites	Rail casks – 6 to 12 MTHM per cask for shipments from 63 sites
		Truck casks – about 1.8 MTHM per cask for shipments from 9 sites	Truck casks – about 1.8 MTHM per cask for shipments from 9 sites
DOE HLW and DOE SNF, except naval SNF	Truck casks – 1 SNF or HLW canister per cask	Rail casks – four to nine SNF or HLW canisters per cask	Rail casks – four to nine SNF or HLW canisters per cask
Naval SNF	Disposal canisters in large rail casks for shipment from INEEL	Disposable canisters in large rail casks for shipments from INEEL	Disposable canisters in large rail casks for shipments from INEEL
Transportation modes			
Commercial SNF	Legal-weight trucks	Direct rail from 44 sites served by railroads to repository	Rail from 44 sites served by railroads to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks from 5 sites to railhead, then rail to repository	Heavy-haul trucks from 5 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository
		Heavy-haul trucks or barges[c] from 14 sites to railhead, then rail to repository	Heavy-haul trucks or barges from 14 sites to railheads, then rail to intermodal transfer station in Nevada, then heavy-haul trucks to repository[e]
		Legal-weight trucks from 9 sites to repository	Legal-weight trucks from 9 sites to repository
DOE HLW and DOE SNF, except naval SNF	Legal-weight trucks	Rail from DOE sites[d] to repository	Rail from DOE sites to intermodal transfer station in Nevada, then heavy-haul trucks to repository
Naval SNF	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository	Rail from INEEL to repository	Rail from INEEL to intermodal transfer station in Nevada, then heavy-haul trucks to repository

a. Abbreviations: SNF = spent nuclear fuel; MTHM = metric tons of heavy metal; HLW = high-level radioactive waste; INEEL = Idaho National Engineering and Environmental Laboratory.
b. G. E. Morris facility is included with the Dresden reactor facilities in the 72 commercial sites.
c. Fourteen of 19 commercial sites not served by a railroad are on or near a navigable waterway. Some of these 14 sites could ship by barge rather than by heavy-haul truck to a nearby railhead.
d. Hanford Site, Savannah River Site, Idaho National Engineering and Environmental Laboratory, West Valley Demonstration Project, and Ft. St. Vrain.

Detailed descriptions of spent nuclear fuel and high-level radioactive waste that would be shipped to the Yucca Mountain site are presented in Appendix A.

J.1.2.1.1 *Commercial Spent Nuclear Fuel*

For the analysis, the CALVIN model used 32 shipping cask configurations: 15 for legal-weight truck casks (Figure J-3) and 17 for rail casks (Figure J-4). Table J-3 lists the legal-weight truck and rail cask configurations used in the analysis and their capacities. The analysis assumed that all shipments would use one of the 32 configurations. If the characteristics of the spent nuclear fuel projected for shipment exceeded the capabilities of one of the casks, the model reduced the cask's capacity for the affected shipments. The reduction, which is sometimes referred to as cask derating, was needed to satisfy nuclear criticality, shielding, and thermal constraints. For shipments that DOE would make using specific casks, derating would be accomplished by partially filling the assigned casks in compliance with provisions of applicable Nuclear Regulatory Commission certificates of compliance. An example of derating is discussed in Section 5 of the GA-4 legal-weight truck shipping cask design report (General Atomics 1993, page 5.5-1). The analysis addresses transport of two high-burnup or short cooling time pressurized-water reactor assemblies rather than four design basis assemblies.

RAIL SHIPMENTS

This appendix assumes that rail shipments of spent nuclear fuel would use large rail shipping casks, one per railcar. DOE anticipates that as many as five railcars with casks containing spent nuclear fuel or high-level radioactive waste would move together in individual trains with buffer cars and escort cars. For general freight service, a train would include other railcars with other materials. In dedicated (or special) service, trains would move only railcars containing spent nuclear fuel or high-level radioactive waste and the buffer and escort cars.

For the mostly rail scenario, 9 sites without sufficient crane capacity to lift a rail cask or without other factors such as sufficient floor loading capacity or ceiling height were assumed to ship by legal-weight truck. The 19 sites with sufficient crane capacity but without direct rail access were assumed to ship by heavy-haul truck to the nearest railhead. Of these 19 sites, 14 with access to navigable waterways were analyzed for shipping by barge to a railhead (see Section J.2.1). The number of rail shipments (direct or indirect) was estimated based on each site using the largest cask size feasible based on the load capacity of its cask handling crane. In calculating the number of shipments from the sites, the model used the DOE allocation of delivery rights (10 CFR Part 961) to the sites and the anticipated receipt rate at the repository listed in Table J-4. Using CALVIN, the number of shipments of legal-weight truck casks (Figure J-3) of commercial spent nuclear fuel estimated for the Proposed Action (63,000 MTU of commercial spent nuclear fuel) for the mostly legal-weight truck scenario, would be about 14,000 containing boiling-water reactor assemblies and 24,000 containing pressurized-water reactor assemblies. Under Inventory Modules 1 and 2, for which approximately 105,000 MTU of commercial spent nuclear fuel would be shipped to the repository (see Appendix A), the estimated number of shipments for the mostly legal-weight truck scenario would be 24,000 for boiling-water reactor spent nuclear fuel and 43,000 for pressurized-water reactor spent nuclear fuel. Table J-5 lists the number of shipments of commercial spent nuclear fuel for the mostly legal-weight truck scenario. Specifically, it lists the site, plant, and state where shipments would originate, the total number of shipments from each site, and the type of spent nuclear fuel that would be shipped. A total of 72 commercial sites with 104 plants (or facilities) are listed in the table.

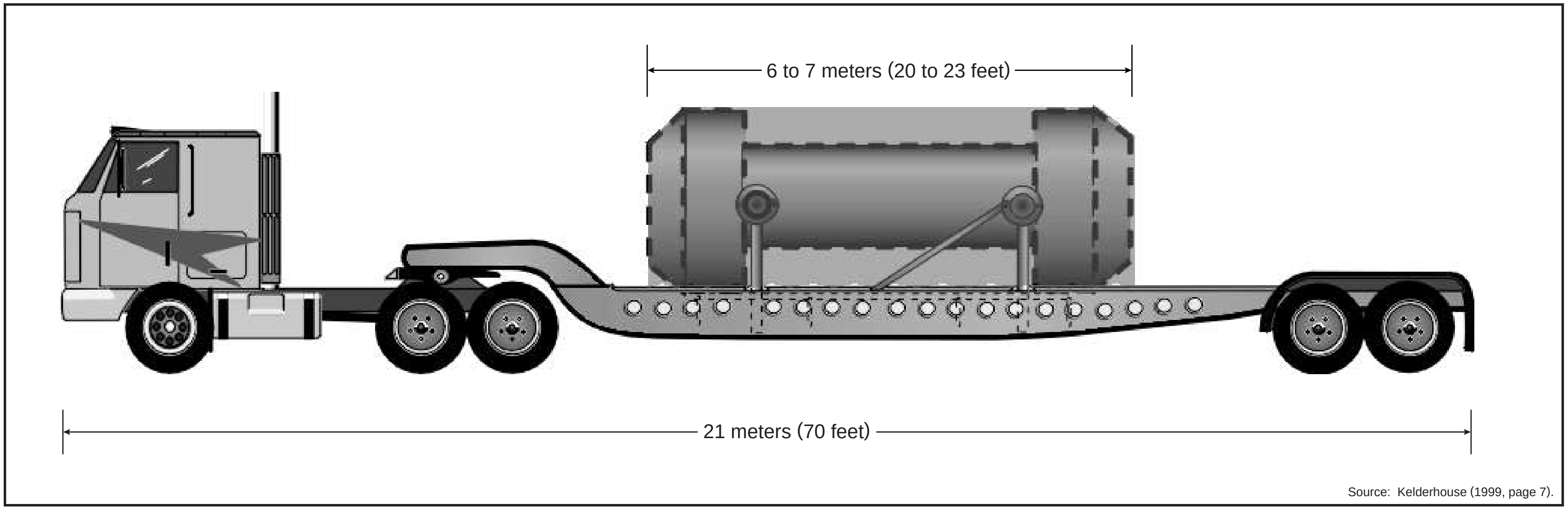


Figure J-3. Artist's conception of a truck cask on a legal-weight tractor-trailer truck.

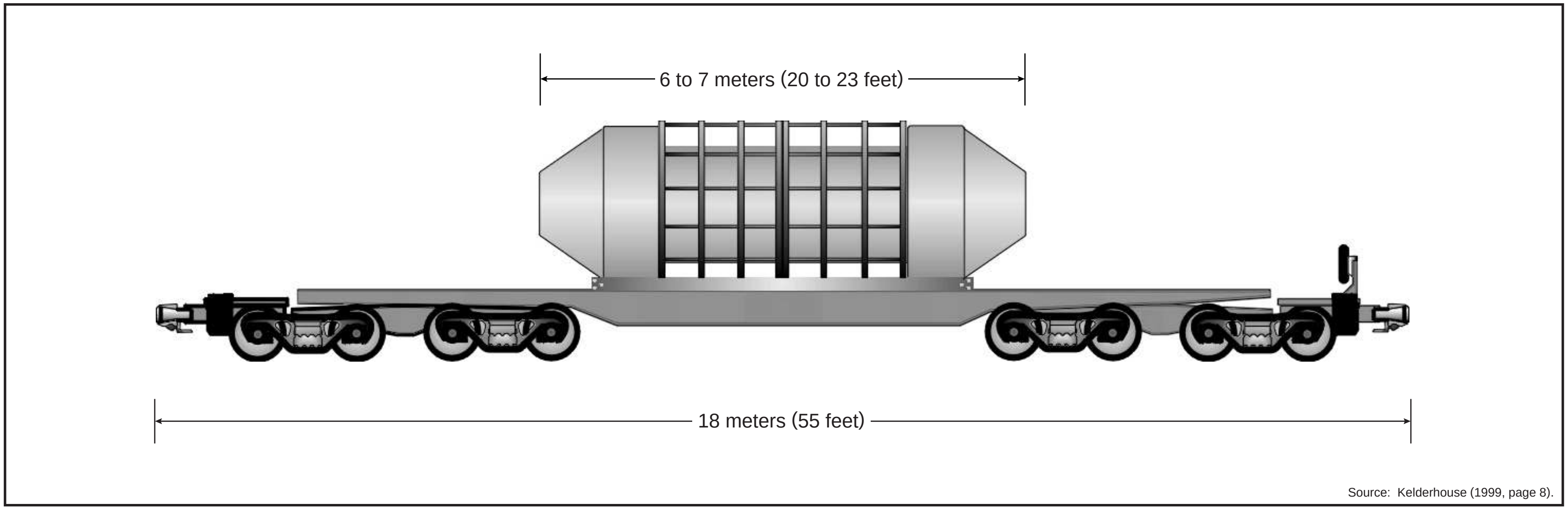


Figure J-4. Artist's conception of a large rail cask on a railcar.

Table J-3. Shipping cask configurations.

Shipping casks	Capacity (number of spent nuclear fuel assemblies)	Description[a,b]
Rail		
B-RAIL-LGSP	61	Large BWR single-purpose shipping container
B-RAIL-SMSP	24	Small BWR single-purpose shipping container
BP-TRAN-OVLG74	74	Big Rock Point dual-purpose shipping container
B-TRAN-OVLG	61	Large BWR dual-purpose shipping container
B-TRAN-OVMED	44	Medium BWR dual-purpose shipping container
B-TRAN OVSM	24	Small BWR dual-purpose shipping container
B-High Heat Rail	17	BWR high heat shipping container
P-RAIL-LGSP	26	Large PWR single-purpose shipping container
P-RAIL-SMSP	12	Small PWR single-purpose shipping container
P-RAIL-MOX	9	Mixed-oxide SNF shipping container
P-RL-LGSP-ST	12	South Texas single-purpose shipping container
P-TRAN-OVLG-YR	36	Yankee Rowe dual-purpose shipping container
P-TRAN-OVLG	24	Large PWR dual-purpose shipping container
P-TRAN-OVMED	21	Medium PWR dual-purpose shipping container
P-TRAN-OVSM	12	Small PWR dual-purpose shipping container
P-TRNST-OVLG	12	South Texas dual-purpose shipping container
P-High Heat-Rail	7	PWR high heat shipping container
Truck		
B-LWT-GA9I	9	Primary BWR shipping container
B-LWT-GA9II	7	Derated BWR shipping container
B-LWT-GA9III	5	Derated BWR shipping container
B-LWT-GA9IV	4	Derated BWR shipping container
B-LWT-GAV	2	Derated BWR shipping container
BP-LWT-GA4I	4	Big Rock Point shipping container
B-NLI-1/2	2	Secondary BWR shipping container
P-LWT-GA4I	4	Primary PWR shipping container
P-LWT-GA4II	3	Derated PWR shipping container
P-LWT-GA4III	2	Derated PWR shipping container
P-LWT-GA4I-ST	4	South Texas shipping container
P-LWT-GA4II-ST	3	Derated South Texas shipping container
P-LWT-GA4III-ST	2	Derated South Texas shipping container
P-NLI-1/2	1	Secondary PWR shipping container
P-LWT-MOX	4	Mixed-oxide SNF shipping container

a. Source: TRW (1999a, page 3).
b. BWR = boiling-water reactor; PWR = pressurized-water reactor; SNF = spent nuclear fuel.

The number of shipments of truck and rail casks (Figure J-4) of commercial spent nuclear fuel estimated for the Proposed Action for the mostly rail scenario would be 4,200 for boiling-water reactor spent nuclear fuel and 6,800 for pressurized-water reactor spent nuclear fuel. Under Modules 1 and 2, the estimated number of shipments for the mostly rail scenario would be 6,500 containing boiling-water reactor spent nuclear fuel and 11,100 containing pressurized-water reactor spent nuclear fuel. Table J-6 lists the number of shipments for the mostly rail scenario. It also lists the site and state where shipments would originate, the total number of shipments from each site, the size of rail cask assumed for each site, and the type of spent nuclear fuel that would be shipped. In addition, it lists the 19 sites not served by a railroad that would ship rail casks by barge or heavy-haul trucks to a nearby railhead and the 9 commercial sites without capability to load a rail cask.

Table J-4. Anticipated receipt rate for spent nuclear fuel and high-level radioactive waste at the Yucca Mountain Repository[a].

	Commercial spent nuclear fuel annual receipt[b]			High-level radioactive waste and DOE spent nuclear fuel[c] annual receipts		
		Shipments			Shipments	
Year	MTHM[d]	Mostly LWT[e]	Mostly rail	MTHM	Mostly LWT	Mostly rail
2010	300	267	100	0	0	0
2011	600	413	184	0	0	0
2012	1,200	757	294	0	0	0
2013	2,000	1,246	478	0	0	0
2014	3,000	1,805	663	0	0	0
2015	3,000	1,792	638	400	650	140
2016	3,000	1,797	600	400	650	140
2017	3,000	1,803	555	400	650	140
2018	3,000	1,787	497	400	650	140
2019	3,000	1,782	508	400	650	140
2020	3,000	1,773	501	400	650	140
2021	3,000	1,780	514	400	650	140
2022	3,000	1,771	513	400	650	140
2023	3,000	1,772	484	400	650	140
2024	3,000	1,796	496	400	650	140
2025	3,000	1,779	472	400	650	140
2026	3,000	1,777	437	400	650	140
2027	3,000	1,793	488	400	650	140
2028	3,000	1,772	469	400	650	140
2029	3,000	1,794	460	400	650	140
2030	3,000	1,768	419	400	675	140
2031	3,000	1,808	451	400	685	140
2032	3,000	1,781	458	200	675	49
2033	1,900	1,125	308	0	0	0
Totals	**63,000**	**37,738**	**10,987**	**7,000**	**12,085**	**2,429**

a. Receipt rates based on assumptions presented in the *Analysis of the Total System Life-Cycle Cost of the Civilian Radioactive Waste Management Program* (DOE 1998a, all) and the results of the CALVIN analysis.
b. Projected spent nuclear fuel acceptance rates (until agreements are reached with purchasers/producers/custodians).
c. DOE spent nuclear fuel at the Idaho National Engineering and Environmental Laboratory to be removed by 2035. Three hundred rail shipments of Navy fuel will be among the early shipments to a DOE receiving facility.
d. MTHM = metric tons of heavy metal.
e. LWT = legal-weight truck.

J.1.2.1.2 *DOE Spent Nuclear Fuel and High-Level Radioactive Waste*

To estimate the number of DOE spent nuclear fuel and high-level radioactive waste shipments, the analysis used the number of handling units or number of canisters and the number of canisters per shipment reported by the DOE sites in 1998 (see Appendix A, page A-34; Jensen 1998, all). To determine the number of shipments of DOE spent nuclear fuel and high-level radioactive waste, the analysis assumed one canister would be shipped in a legal-weight truck cask. For rail shipments, the analysis assumed that five 61-centimeter (24-inch)-diameter high-level radioactive waste canisters would be shipped in a rail cask. For rail shipments of DOE spent nuclear fuel, the analysis assumed that rail casks would contain nine approximately 46-centimeter (18-inch) canisters or four approximately 61-centimeter canisters. The number of DOE spent nuclear fuel canisters of each size is presented in Appendix A.

Table J-5. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Browns Ferry	Browns Ferry 1	AL	B[b]	856	1,465
	Browns Ferry 3	AL	B	319	602
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	336	544
	Joseph M. Farley 2	AL	P	297	582
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	302	438
	Arkansas Nuclear One, Unit 2	AR	P	332	525
Palo Verde	Palo Verde 1	AZ	P	345	797
	Palo Verde 2	AZ	P	364	840
	Palo Verde 3	AZ	P	309	861
Diablo Canyon	Diablo Canyon 1	CA	P	327	617
	Diablo Canyon 2	CA	P	305	691
Humboldt Bay	Humboldt Bay	CA	B	44	44
Rancho Seco	Rancho Seco 1	CA	P	124	124
San Onofre	San Onofre 1	CA	P	52	52
	San Onofre 2	CA	P	402	600
	San Onofre 3	CA	P	413	632
Haddam Neck	Haddam Neck	CT	P	255	255
Millstone	Millstone 1	CT	B	463	543
	Millstone 2	CT	P	358	551
	Millstone 3	CT	P	245	575
Crystal River	Crystal River 3	FL	P	283	442
St. Lucie	St. Lucie 1	FL	P	389	571
	St. Lucie 2	FL	P	292	515
Turkey Point	Turkey Point 3	FL	P	295	413
	Turkey Point 4	FL	P	287	458
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	871	1,334
Vogtle	Vogtle 1	GA	P	593	1,462
Duane Arnold	Duane Arnold	IA	B	279	420
Braidwood	Braidwood 1	IL	P	615	1,494
Byron	Byron 1	IL	P	617	1,444
Clinton	Clinton 1	IL	B	296	690
Dresden/Morris	Dresden 1	IL	B	76	76
	Dresden 2	IL	B	430	521
	Dresden 3	IL	B	473	565
	Morris[d]	IL	B	319	319
	Morris[d]	IL	P	88	88
LaSalle	LaSalle 1	IL	B	596	1,261
Quad Cities	Quad Cities 1	IL	B	798	1,123
Zion	Zion 1	IL	P	771	1,028
Wolf Creek	Wolf Creek 1	KS	P	349	708
River Bend	River Bend 1	LA	B	324	823
Waterford	Waterford 3	LA	P	313	675
Pilgrim	Pilgrim 1	MA	B	316	476
Yankee-Rowe	Yankee-Rowe 1	MA	P	134	134
Calvert Cliffs	Calvert Cliffs 1	MD	P	757	1,140
Maine Yankee	Maine Yankee	ME	P	356	356
Big Rock Point	Big Rock Point	MI	B	131	131
D. C. Cook	D. C. Cook 1	MI	P	824	1,235
Fermi	Fermi 2	MI	B	312	764
Palisades	Palisades	MI	P	367	454
Monticello	Monticello	MN	B	267	342
Prairie Island	Prairie Island 1	MN	P	572	805
Callaway	Callaway 1	MO	P	392	735
Grand Gulf	Grand Gulf 1	MS	B	516	1,016
Brunswick	Brunswick 1	NC	P	40	40
	Brunswick 2	NC	P	36	36

Table J-5. Shipments of commercial spent nuclear fuel, mostly legal-weight truck scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Proposed Action (2010-2033)	Modules 1 and 2 (2010-2048)
Brunswick (continued)					
	Brunswick 1	NC	B[b]	232	426
	Brunswick 2	NC	B	232	401
Shearon Harris	Shearon Harris 1	NC	P[c]	298	769
	Shearon Harris	NC	B	152	152
McGuire	McGuire 1	NC	P	387	690
	McGuire 2	NC	P	436	774
Cooper Station	Cooper Station	NE	B	274	454
Fort Calhoun	Fort Calhoun	NE	P	258	362
Seabrook	Seabrook 1	NH	P	235	630
Oyster Creek	Oyster Creek 1	NJ	B	424	519
Salem/Hope Creek	Salem 1	NJ	P	330	545
	Salem 2	NJ	P	298	571
	Hope Creek	NJ	B	399	876
James A. FitzPatrick/ Nine Mile Point	James A. FitzPatrick	NY	B	364	554
	Nine Mile Point 1	NY	B	401	499
	Nine Mile Point 2	NY	B	329	918
Ginna	Ginna	NY	P	309	379
Indian Point	Indian Point 1	NY	P	40	40
	Indian Point 2	NY	P	364	590
	Indian Point 3	NY	P	297	525
Davis-Besse	Davis-Besse 1	OH	P	286	535
Perry	Perry 1	OH	B	288	631
Trojan	Trojan	OR	P	195	195
Beaver Valley	Beaver Valley 1	PA	P	330	534
	Beaver Valley 2	PA	P	221	622
Limerick	Limerick 1	PA	B	693	1,722
Peach Bottom	Peach Bottom 2	PA	B	480	696
	Peach Bottom 3	PA	B	444	712
Susquehanna	Susquehanna 1	PA	B	808	1,582
Three Mile Island	Three Mile Island 1	PA	P	287	435
Catawba	Catawba 1	SC	P	325	663
	Catawba 2	SC	P	318	667
Oconee	Oconee 1	SC	P	727	1,043
	Oconee 3	SC	P	280	457
H. B. Robinson	H. B. Robinson 2	SC	P	231	306
Summer	Summer 1	SC	P	291	538
Sequoyah	Sequoyah	TN	P	560	1,179
Watts Bar	Watts Bar 1	TN	P	146	840
Comanche Peak	Comanche Peak 1	TX	P	559	1,558
South Texas	South Texas 1	TX	P	256	738
	South Texas 2	TX	P	229	710
North Anna	North Anna 1	VA	P	634	1,079
Surry	Surry 1	VA	P	647	902
Vermont Yankee	Vermont Yankee 1	VT	B	369	484
WPPSS[e] 2	WPPSS 2	WA	B	353	736
Kewaunee	Kewaunee	WI	P	288	401
LaCrosse	LaCrosse	WI	B	37	37
Point Beach	Point Beach	WI	P	575	742
Total BWR[b]				**13,965**	**23,914**
Total PWR[c]				**23,773**	**42,936**

a. Source: TRW (1999a, Section 2).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.
e. WPPSS = Washington Public Power Supply System.

Table J-6. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 1 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Browns Ferry	Browns Ferry 1	AL	B[b]	Medium	239	422
	Browns Ferry 3	AL	B	Medium	88	168
Joseph M. Farley	Joseph M. Farley 1	AL	P[c]	Large	54	78
	Joseph M. Farley 2	AL	P	Large	49	79
Arkansas Nuclear One	Arkansas Nuclear One, Unit 1	AR	P	Medium	81	115
	Arkansas Nuclear One, Unit 2	AR	P	Medium	89	137
Palo Verde	Palo Verde 1	AZ	P	Large	53	120
	Palo Verde 2	AZ	P	Large	56	124
	Palo Verde 3	AZ	P	Large	47	106
Diablo Canyon	Diablo Canyon 1	CA	P	Medium	103	169
	Diablo Canyon 2	CA	P	Medium	97	174
Humboldt Bay	Humboldt Bay	CA	B	Truck	44	44
Rancho Seco	Rancho Seco 1	CA	P	Large	21	21
San Onofre	San Onofre 1	CA	P	Large	9	8
	San Onofre 2	CA	P	Large	66	97
	San Onofre 3	CA	P	Large	68	102
Haddam Neck	Haddam Neck	CT	P	Truck	255	255
Millstone	Millstone 1	CT	B	Small	174	204
	Millstone 2	CT	P	Small	120	183
	Millstone 3	CT	P	Medium	73	137
Crystal River	Crystal River 3	FL	P	Truck	283	442
St. Lucie	St. Lucie 1	FL	P	Truck	389	571
	St. Lucie 2	FL	P	Medium	88	140
Turkey Point	Turkey Point 3	FL	P	Medium	73	111
	Turkey Point 4	FL	P	Medium	72	117
Edwin I. Hatch	Edwin I. Hatch 1	GA	B	Large	128	197
Vogtle	Vogtle 1	GA	P	Small	195	431
Duane Arnold	Duane Arnold	IA	B	Small	105	158
Braidwood	Braidwood 1	IL	P	Large	95	215
Byron	Byron 1	IL	P	Large	136	244
Clinton	Clinton 1	IL	B	Medium	103	200
Dresden/Morris	Dresden 1	IL	B	Small	29	29
	Dresden 2	IL	B	Small	162	193
	Dresden 3	IL	B	Small	177	208
	Morris[d]	IL	B	Large	47	47
	Morris[d]	IL	P	Large	14	14
LaSalle	LaSalle 1	IL	B	Large	89	172
Quad Cities	Quad Cities 1	IL	B	Small	299	419
Zion	Zion 1	IL	P	Medium	147	250
Wolf Creek	Wolf Creek 1	KS	P	Large	52	106
River Bend	River Bend 1	LA	B	Large	48	101
Waterford	Waterford 3	LA	P	Large	49	91
Pilgrim	Pilgrim 1	MA	B	Truck	316	476
Yankee-Rowe	Yankee-Rowe 1	MA	P	Large	15	15
Calvert Cliffs	Calvert Cliffs 1	MD	P	Medium	198	303
Maine Yankee	Maine Yankee	ME	P	Large	60	60
Big Rock Point	Big Rock Point	MI	B	Large	8	8
D. C. Cook	D. C. Cook 1	MI	P	Medium	214	346
Fermi	Fermi 2	MI	B	Medium	100	199
Palisades	Palisades	MI	P	Medium	78	117
Monticello	Monticello	MN	B	Truck	267	342
Prairie Island	Prairie Island 1	MN	P	Medium	151	221
Callaway	Callaway 1	MO	P	Large	62	114
Grand Gulf	Grand Gulf 1	MS	B	Large	76	143

Table J-6. Shipments of commercial spent nuclear fuel, mostly rail scenario[a] (page 2 of 2).

Site	Reactor	State	Fuel type	Cask	Proposed Action 2010 - 2033	Modules 1 and 2 2010 - 2048
Brunswick	Brunswick 1	NC	P[c]	Small	14	14
	Brunswick 2	NC	P	Small	12	12
	Brunswick 1	NC	B[b]	Small	88	150
	Brunswick 2	NC	B	Small	87	145
Shearon Harris	Shearon Harris 1	NC	P	Small	93	201
	Shearon Harris	NC	B	Small	57	57
McGuire	McGuire 1	NC	P	Medium	115	199
	McGuire 2	NC	P	Medium	138	228
Cooper Station	Cooper Station	NE	B	Small	103	166
Fort Calhoun	Fort Calhoun	NE	P	Small	87	121
Seabrook	Seabrook 1	NH	P	Large	37	83
Oyster Creek	Oyster Creek 1	NJ	B	Medium	108	151
Salem/Hope Creek	Salem 1	NJ	P	Medium	97	153
	Salem 2	NJ	P	Medium	83	143
	Hope Creek	NJ	B	Large	59	125
James A. FitzPatrick/ Nine Mile Point	FitzPatrick	NY	B	Large	54	79
	Nine Mile Point 1	NY	B	Medium	135	167
	Nine Mile Point 2	NY	B	Medium	101	206
Ginna	Ginna	NY	P	Truck	309	379
Indian Point	Indian Point 1	NY	P	Truck	40	40
	Indian Point 2	NY	P	Truck	364	590
	Indian Point 3	NY	P	Truck	297	525
Davis-Besse	Davis-Besse 1	OH	P	Large	44	71
Perry	Perry 1	OH	B	Large	42	82
Trojan	Trojan	OR	P	Large	33	33
Beaver Valley	Beaver Valley 1	PA	P	Large	52	81
	Beaver Valley 2	PA	P	Large	34	79
Limerick	Limerick 1	PA	B	Medium	262	497
Peach Bottom	Peach Bottom 2	PA	B	Medium	138	206
	Peach Bottom 3	PA	B	Medium	127	197
Susquehanna	Susquehanna 1	PA	B	Large	119	219
Three Mile Island	Three Mile Island 1	PA	P	Medium	71	113
Catawba	Catawba 1	SC	P	Large	72	123
	Catawba 2	SC	P	Large	76	130
Oconee	Oconee 1	SC	P	Medium	187	266
	Oconee 3	SC	P	Medium	67	107
H. B. Robinson	H. B. Robinson 2	SC	P	Small	75	97
Summer	Summer 1	SC	P	Large	46	82
Sequoyah	Sequoyah	TN	P	Large	90	161
Watts Bar	Watts Bar 1	TN	P	Large	21	121
Comanche Peak	Comanche Peak 1	TX	P	Large	90	246
South Texas	South Texas 1	TX	P	Large	79	180
	South Texas 2	TX	P	Large	72	178
North Anna	North Anna 1	VA	P	Large	101	167
Surry	Surry 1	VA	P	Large	105	144
Vermont Yankee	Vermont Yankee 1	VT	B	Small	139	182
WPPSS[e] 2	WPPSS 2	WA	B	Large	53	107
Kewaunee	Kewaunee	WI	P	Medium	73	106
La Crosse	La Crosse	WI	B	Truck	37	37
Point Beach	Point Beach	WI	P	Large	93	118
Total BWR[b]					**4,208**	**6,503**
Total PWR[c]					**6,779**	**11,104**

a. Source: TRW (1999a, Section 2).
b. B = boiling-water reactor (BWR).
c. P = pressurized-water reactor (PWR).
d. Morris is a storage facility located close to the three Dresden reactors.
e. WPPSS = Washington Public Power Supply System.

Under the mostly legal-weight truck scenario for the Proposed Action, a total of about 11,800 truck shipments of DOE spent nuclear fuel and high-level radioactive waste would be shipped to the repository. In addition, due to the size and weight of the shipping casks for canisters that would contain naval spent fuel, DOE would transport 300 shipments of naval spent fuel by rail from the Idaho National Engineering and Environmental Laboratory to the repository. For Modules 1 and 2, under the mostly legal-weight truck scenario, the analysis estimated 3,740 DOE spent nuclear fuel and 22,300 high-level radioactive waste truck shipments and 300 naval spent nuclear fuel shipments by rail.

Under the mostly rail scenario for the Proposed Action, the analysis estimated that 770 railcar shipments of DOE spent nuclear fuel, including 300 railcar shipments of naval spent nuclear fuel (one naval spent nuclear fuel canister per rail cask), and 1,660 railcar shipments of high-level waste would travel to the repository. For Modules 1 and 2, under this scenario 800 railcar shipments of DOE spent nuclear fuel, including 300 railcar shipments of naval spent nuclear fuel, and 4,460 railcar shipments of high-level radioactive waste would be shipped. Table J-7 lists the estimated number of shipments of DOE spent nuclear fuel from each of the four sites for both the Proposed Action and Modules 1 and 2. Table J-8 lists the number of shipments of high-level radioactive waste for the Proposed Action and for Modules 1 and 2.

Table J-7. DOE spent nuclear fuel shipments by site.

	Proposed Action		Module 1 or 2	
Site	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a,b]	1,388	434	1,467	443
Savannah River Site	1,316	149	1,411	159
Hanford	754	147	809	157
Fort St. Vrain	312	36	334	38
Totals	**3,770**	**766**	**4,021**	**797**

a. INEEL = Idaho National Engineering and Environmental Laboratory.
b. Includes 300 railcar shipments of naval spent nuclear fuel.

Table J-8. Number of canisters of high-level radioactive waste and shipments from DOE sites.

	Proposed Action			Module 1 or 2	
Site	Canisters	Mostly truck	Mostly rail	Mostly truck	Mostly rail
INEEL[a]	1,300	0	0	1,300	260
Hanford	14,500	1,960	400	14,500	2,900
Savannah River Site	6,200	6,055	1,200	6,200	1,240
West Valley[b]	300	300	60	300	60
Totals	**22,300**	**8,315**	**1,660**	**22,300**	**4,460**

a. INEEL = Idaho National Engineering and Environmental Laboratory.
b. High-level radioactive waste at West Valley is commercial rather than DOE waste.

J.1.2.1.3 *Greater-Than-Class-C and Special-Performance-Assessment-Required Waste Shipments*

Reasonably foreseeable future actions could include shipment of Greater-Than-Class-C and Special-Performance-Assessment-Required waste to the Yucca Mountain Repository (Appendix A describes Greater-Than-Class-C and Special-Performance-Assessment-Required wastes). Commercial nuclear powerplants, research reactors, radioisotope manufacturers, and other manufacturing and research institutions generate low-level radioactive waste that exceeds the Nuclear Regulatory Commission Class

C shallow-land-burial disposal limits. In addition to DOE-held material, there are three other sources or categories of Greater-Than-Class-C low-level radioactive waste:

- Nuclear utilities
- Sealed sources
- Other generators

The activities of nuclear electric utilities and other radioactive waste generators to date have produced relatively small quantities of Greater-Than-Class-C low-level radioactive waste. As the utilities take their reactors out of service and decommission them, they could generate more waste of this type.

DOE Special-Performance-Assessment-Required low-level radioactive waste could include the following materials:

- Production reactor operating wastes
- Production and research reactor decommissioning wastes
- Non-fuel-bearing components of naval reactors
- Sealed radioisotope sources that exceed Class C limits for waste classification
- DOE isotope production-related wastes
- Research reactor fuel assembly hardware

The analysis estimated the number of shipments of Greater-Than-Class-C and Special-Performance-Assessment-Required waste by assuming that 10 cubic meters (about 350 cubic feet) would be shipped in a rail cask and 2 cubic meters (about 71 cubic feet) would be shipped in a truck cask. Table J-9 lists the resulting number of commercial Greater-Than-Class-C shipments in Inventory Module 2 for both truck and rail shipments. The shipments of Greater-Than-Class-C waste from commercial utilities would originate among the commercial reactor sites. Typically, boiling-water reactors would ship a total of about 9 cubic meters (about 318 cubic feet) of Greater-Than-Class-C waste per site, while pressurized-water reactors would ship about 20 cubic meters (about 710 cubic feet) per site (see Appendix A). The impacts of transporting this waste were examined for each reactor site. The analysis assumed that sealed sources and Greater-Than-Class-C waste identified as "other" would be shipped from the DOE Savannah River Site (see Table J-10).

Table J-9. Commercial Greater-Than-Class-C waste shipments.

Category	Volume (cubic meters)[a,b]	Truck	Rail
Commercial utilities	1,350	740	210
Sealed sources	240	120	25
Other	470	230	50
Total	**2,060**	**1,090**	**285**

a. Source: Appendix A.
b. To convert cubic meters to cubic feet, multiply by 35.314.

The analysis assumed DOE Special-Performance-Assessment-Required waste would be shipped from 4 DOE sites listed in Table J-10. Naval reactor and Argonne East Special-Performance-Assessment-Required waste is assumed to be shipped from the Idaho National Engineering and Environmental Laboratory.

J.1.2.1.4 *Sensitivity of Transportation Impacts to Number of Shipments*

As discussed in Section J.1.2.1, the number of shipments from commercial and DOE sites to the repository would depend on the mix of legal-weight truck and rail shipments. Because DOE has decided

Table J-10. DOE Special-Performance-Assessment-Required waste shipments.

Site[a]	Volume (cubic meters)[b,c]	Rail	Truck
Hanford	20	2	10
INEEL	520	57[d]	260
SRS (ORNL)	2,900	290	1,470
West Valley	550	56	280
Total	**3,990**	**405**	**2,020**

a. Abbreviations: INEEL = Idaho National Engineering and Environmental Laboratory; SRS = Savannah River Site; ORNL = Oak Ridge National Laboratory.
b. Source: Appendix A.
c. To convert cubic meters to cubic feet, multiply by 35.314.
d. Includes 55 shipments from naval reactors.

not to determine this mix at this time (10 years before the projected start of shipping operations), the analysis used two scenarios to provide results that bound the range of anticipated impacts. Thus, for a mix of legal-weight truck and rail shipments within the range of the mostly legal-weight truck and mostly rail scenarios, the impacts would be likely to lie within the bounds of the impacts predicted by the analysis. For example, a mix that is different from the scenarios analyzed could consist of 5,000 legal-weight truck shipments and 9,000 rail shipments over 24 years (compared to 2,600 and 10,800, respectively, for the mostly rail scenario). In this example, the number of traffic fatalities would be between 3.6 (estimated for the Proposed Action under the mostly rail scenario) and 3.9 (estimated for the mostly legal-weight truck scenario). Other examples that have different mixes within the ranges bounded by the scenarios would lead to results that would be within the range of the evaluated impacts.

In addition to mixes within the brackets, the number of shipments could fall outside the ranges used for the mostly legal-weight truck and rail transportation scenarios. If, for example, the mostly rail scenario used smaller rail casks than the analysis assumed, the number of shipments would be greater. If spent nuclear fuel was placed in the canisters before they were shipped, the added weight and size of the canisters would reduce the number of fuel assemblies that a given cask could accommodate; this would increase the number of shipments. However, for the mostly rail scenario, even if the capacity of the casks was half that used in the analysis, the impacts would remain below those forecast for the mostly legal-weight truck scenario. Although impacts would be related to the number of shipments, because the number of rail shipments would be very small in comparison to the total railcar traffic on the Nation's railroads, increases or decreases would be small for impacts to biological resources, air quality, hydrology, noise, and other environmental resource areas. Thus, the impacts of using smaller rail casks would be covered by the values estimated in this EIS.

For legal-weight truck shipments, the use of casks carrying smaller payloads than those used in the analysis (assuming the shipment of the same spent nuclear fuel) would lead to larger impacts for incident-free transportation and traffic fatalities and about the same level of radiological accident risk. The relationship is approximately linear; if the payloads of truck shipping casks in the mostly legal-weight truck scenario were less by one-half, the incident-free impacts would increase by approximately a factor of 2. Conversely, because the amount of radioactive material in a cask would be less (assuming shipment of the same spent nuclear fuel), the radiological consequences of maximum reasonably foreseeable accident scenarios would be less with the use of smaller casks. If smaller casks were used to accommodate shipments of spent nuclear fuel with shorter cooling time and higher burnup, the radiological consequences of maximum reasonably foreseeable accident scenarios would be about the same.

J.1.2.2 Transportation Routes

At this time, about 10 years before shipments could begin, DOE has not determined the specific routes it would use to ship spent nuclear fuel and high-level radioactive waste to the proposed repository. Nonetheless, this analysis used current regulations governing highway shipments and historic rail industry practices to select existing highway and rail routes to estimate potential environmental impacts of national transportation. Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with applicable regulations of the Department of Transportation and the Nuclear Regulatory Commission in effect at the time the shipments occurred, as stated in the proposed DOE revised policy and procedures for implementing Section 180(c) of the Nuclear Waste Policy Act (DOE 1998b, all).

Approximately 4 years before shipments to the proposed repository began, the Office of Civilian Radioactive Waste Management plans to identify the preliminary routes that DOE anticipates using in state and tribal jurisdictions so it can notify governors and tribal leaders of their eligibility for assistance under the provisions of Section 180(c) of the Nuclear Waste Policy Act. DOE has published a revised proposed policy statement that sets forth its revised plan for implementing a program of technical and financial assistance to states and Native American tribes for training public safety officials of appropriate units of local government and tribes through whose jurisdictions the Department plans to transport spent nuclear fuel or high-level radioactive waste (63 *FR* 83, January 2, 1998).

The analysis of impacts of the Proposed Action and Modules 1 and 2 used characteristics of routes that shipments of spent nuclear fuel and high-level radioactive waste could travel from the originating sites listed in Tables J-5 through J-8. Existing routes that could be used were identified for the mostly legal-weight truck and mostly rail transportation scenarios and included the 10 rail and heavy-haul truck implementing alternatives evaluated in the EIS for transportation in Nevada. The route characteristics used were the transportation mode (highway, railroad, or navigable waterway) and, for each of the modes, the total distance between an originating site and the repository. In addition, the analysis estimated the fraction of travel that would occur in rural, suburban, and urban areas for each route. The fraction of travel in each population zone was determined using 1990 census data (see Section J.1.1.2 and J.1.1.3) to identify population-zone impacts for route segments. The highway routes were selected for the analysis using the HIGHWAY computer program and routing requirements of the Department of Transportation for shipments of Highway Route-Controlled Quantities of Radioactive Materials (49 CFR 397.101). Shipments of spent nuclear fuel and high-level radioactive waste would contain Highway Route-Controlled Quantities of Radioactive Materials.

J.1.2.2.1 *Routes Used in the Analysis*

Routes used in the analysis of transportation impacts of the Proposed Action and Inventory Modules 1 and 2 are highways and rail lines that DOE anticipates it could use for legal-weight truck or rail shipments from each origin to Nevada. For rail shipments that would originate at sites not served by railroads, routes used for analysis include highway routes for heavy-haul trucks or barge routes from the sites to railheads. Figures J-5 and J-6 show the Interstate System highways and mainline railroads, respectively, and their relationship to the commercial and DOE sites and Yucca Mountain. Tables J-11 and J-12 list the lengths of trips and the distances of the highway and rail routes, respectively, in rural, suburban, and urban population zones. Sites that would be capable of loading rail casks, but that do not have direct rail access, are listed in Table J-12. The analysis used four ending rail nodes in Nevada (Beowawe, Caliente, Jean, and Apex) to select rail routes from the 77 sites. These rail nodes would be starting points for the rail and heavy-haul truck implementing alternatives analyzed for transportation in Nevada.

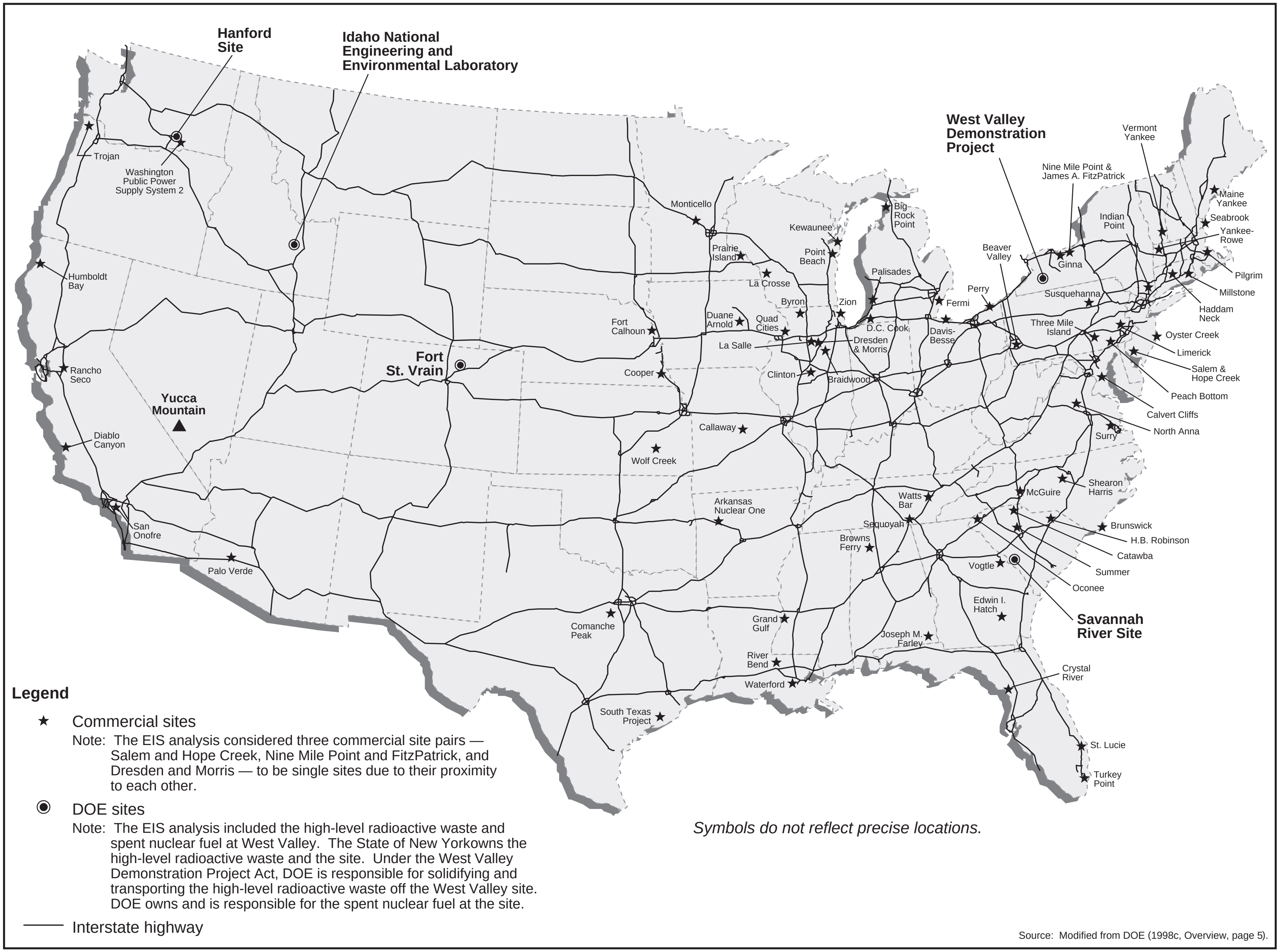


Figure J-5. Commercial and DOE sites and Yucca Mountain in relation to the U.S. Interstate Highway System.

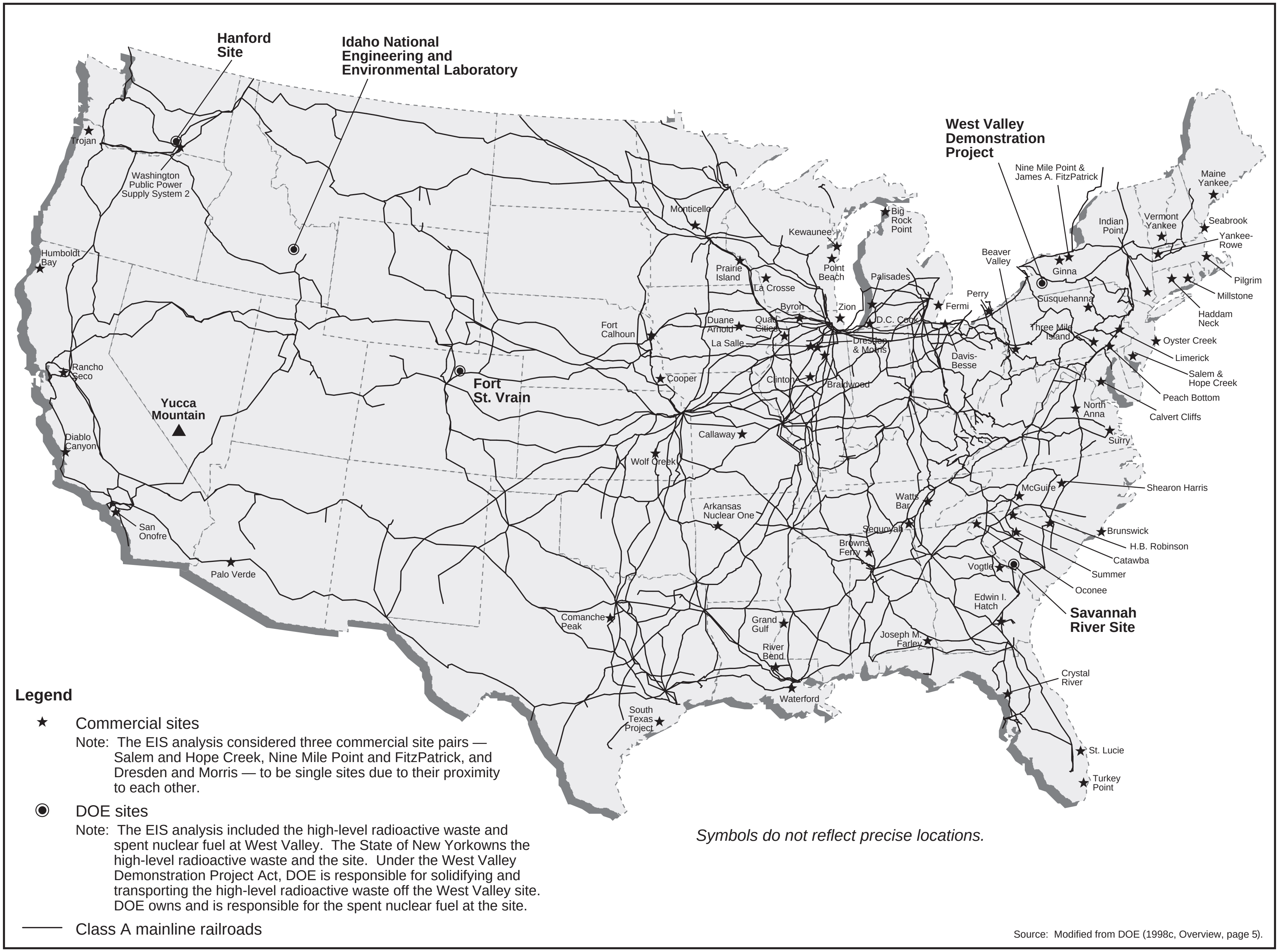


Figure J-6. Commercial and DOE sites and Yucca Mountain in relation to the U.S. railroad system.

Table J-11. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 1 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Browns Ferry	AL	3,442	3,022	374	45
Joseph M. Farley	AL	4,229	3,647	520	62
Arkansas Nuclear One	AR	2,810	2,588	192	30
Palo Verde	AZ	1,007	886	100	21
Diablo Canyon	CA	1,016	828	119	68
Humboldt Bay	CA	1,749	1,465	192	92
Rancho Seco	CA	1,228	1,028	124	76
San Onofre	CA	694	517	89	88
Haddam Neck	CT	4,519	3,708	736	75
Millstone	CT	4,527	3,673	746	109
Crystal River	FL	4,319	3,606	653	59
St. Lucie	FL	4,588	3,793	729	64
Turkey Point	FL	4,842	3,888	821	132
Edwin I. Hatch	GA	3,986	3,373	553	58
Vogtle	GA	3,938	3,301	573	63
Duane Arnold	IA	2,773	2,544	189	40
Braidwood	IL	3,063	2,796	231	36
Byron	IL	3,032	2,773	223	36
Clinton	IL	3,104	2,814	252	38
Dresden/Morris	IL	3,059	2,798	225	36
La Salle	IL	3,017	2,766	215	36
Quad Cities	IL	2,877	2,631	211	36
Zion	IL	3,167	2,834	284	50
Wolf Creek	KS	2,374	2,226	131	16
River Bend	LA	3,446	2,941	420	85
Waterford	LA	3,531	3,003	444	84
Pilgrim	MA	4,722	3,697	930	94
Yankee-Rowe	MA	4,616	3,692	831	92
Calvert Cliffs	MD	4,278	3,511	684	82
Maine Yankee	ME	4,894	3,733	1,052	108
Big Rock Point	MI	3,866	3,266	547	52
D. C. Cook	MI	3,196	2,827	319	51
Fermi	MI	3,524	3,014	449	61
Palisades	MI	3,244	2,855	338	51
Monticello	MN	3,003	2,702	261	41
Prairie Island	MN	2,993	2,720	233	41
Callaway	MO	2,633	2,399	206	27
Grand Gulf	MS	3,354	2,989	311	54
Brunswick	NC	4,418	3,672	680	66
Shearon Harris	NC	4,187	3,493	630	63
McGuire	NC	3,991	3,415	516	58
Cooper Station	NE	2,523	2,328	160	36
Fort Calhoun	NE	2,348	2,165	148	35
Seabrook	NH	4,725	3,676	942	107
Oyster Creek	NJ	4,424	3,530	825	69
Salem/Hope Creek	NJ	4,350	3,531	739	79
Ginna	NY	4,089	3,357	642	91
Indian Point	NY	4,382	3,695	620	67
James FitzPatrick/Nine Mile Point	NY	4,234	3,461	688	85

Table J-11. Highway distances for legal-weight truck shipments from commercial and DOE sites to Yucca Mountain, mostly legal-weight truck transportation (kilometers)[a,b] (page 2 of 2).

Origin	State	Total[c]	Rural	Suburban	Urban
Davis-Besse	OH	3,520	3,106	358	56
Perry	OH	3,693	3,157	464	73
Trojan	OR	2,137	1,865	237	36
Beaver Valley	PA	3,779	3,215	500	64
Limerick	PA	4,287	3,484	741	62
Peach Bottom	PA	4,205	3,479	662	64
Susquehanna	PA	4,126	3,539	528	59
Three Mile Island	PA	4,147	3,443	643	60
Catawba	SC	3,994	3,364	575	54
Oconee	SC	3,853	3,264	532	55
H. B. Robinson	SC	4,112	3,417	628	65
Summer	SC	3,996	3,383	557	55
Sequoyah	TN	3,500	3,039	414	45
Watts Bar	TN	3,578	3,138	394	45
Comanche Peak	TX	2,794	2,547	213	34
South Texas	TX	3,011	2,652	295	64
North Anna	VA	4,081	3,503	515	63
Surry	VA	4,255	3,577	610	67
Vermont Yankee	VT	4,616	3,675	847	94
WPPSS[d] 2	WA	1,880	1,669	178	32
Kewaunee	WI	3,347	2,979	314	55
La Crosse	WI	3,014	2,773	198	43
Point Beach	WI	3,341	2,972	314	55
Ft. St. Vrain[e]	CO	1,415	1,311	93	10
INEEL[f]	ID	1,201	1,044	130	27
West Valley[g]	NY	3,959	3,322	562	75
Savannah River[f]	SC	3,961	3,321	574	64
Hanford[g]	WA	1,881	1,671	178	32

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances determined for purposes of analysis using HIGHWAY computer program.
c. Totals might differ from sums due to method of calculation and rounding.
d. DOE spent nuclear fuel site.
e. DOE spent nuclear fuel and high-level waste site.
f. DOE high-level waste site.
g. WPPSS = Washington Public Power Supply System.

STATE-DESIGNATED PREFERRED ROUTES

Department of Transportation regulations specify that states and tribes can designate preferred routes that are alternatives, or in addition to, Interstate System highways including bypasses or beltways for the transportation of Highway Route-Controlled Quantities of Radioactive Materials. Highway Route-Controlled Quantities of Radioactive Materials include spent nuclear fuel and high-level radioactive waste in quantities that would be shipped on a truck or railcar to the repository. If a state or tribe designated such a route, shipments of spent nuclear fuel and high-level radioactive waste would use the preferred route if (1) it was an alternative preferred route, (2) it would result in reduced time in transit, or (3) it would replace pickup or delivery routes. Ten states—Alabama, Arkansas, California, Colorado, Iowa, Kentucky, Nebraska, New Mexico, Tennessee, and Virginia—have designated alternative or additional preferred routes (Rodgers 1998, all). Although Nevada has designated a State routing agency to the Department of Transportation (Nevada Revised Statutes, Chapter 408.141), the State has not designated alternative preferred routes for Highway Route-Controlled Quantities of Radioactive Materials.

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 1 of 5)

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access						
Joseph M. Farley	AL	Apex	4,495	3,872	562	60
		Caliente	4,322	3,698	562	60
		Beowawe	4,177	3,593	535	48
		Jean	4,577	3,937	574	65
Arkansas Nuclear One	AR	Apex	3,170	2,960	181	29
		Caliente	2,996	2,786	181	29
		Beowawe	2,852	2,681	154	17
		Jean	3,251	3,024	193	34
Palo Verde	AZ	Apex	976	864	89	23
		Caliente	1,149	1,038	89	23
		Beowawe	1,908	1,524	274	109
		Jean	894	800	77	18
Rancho Seco	CA	Apex	985	781	151	53
		Caliente	1,159	955	151	53
		Beowawe	706	589	83	32
		Jean	904	717	139	48
San Onofre	CA	Apex	576	409	105	63
		Caliente	750	582	105	63
		Beowawe	1,576	1,167	286	121
		Jean	495	344	93	58
Millstone	CT	Apex	4,728	3,526	994	208
		Caliente	4,555	3,353	994	208
		Beowawe	4,411	3,247	966	197
		Jean	4,810	3,591	1,005	213
Edwin I. Hatch	GA	Apex	4,403	3,830	514	58
		Caliente	4,229	3,656	514	58
		Beowawe	4,085	3,551	486	47
		Jean	4,484	3,894	525	64
Vogtle	GA	Apex	4,459	3,877	523	58
		Caliente	4,286	3,703	523	58
		Beowawe	4,141	3,598	495	47
		Jean	4,541	3,942	534	64
Duane Arnold	IA	Apex	2,745	2,547	167	31
		Caliente	2,572	2,374	167	31
		Beowawe	2,428	2,268	140	20
		Jean	2,827	2,612	178	36
Braidwood	IL	Apex	3,166	2,798	284	85
		Caliente	2,993	2,624	285	85
		Beowawe	2,849	2,518	257	73
		Jean	3,248	2,862	296	90
Byron	IL	Apex	2,979	2,740	205	35
		Caliente	2,806	2,566	205	35
		Beowawe	2,662	2,461	177	24
		Jean	3,061	2,805	216	41
Clinton	IL	Apex	3,172	2,891	228	53
		Caliente	2,998	2,718	228	53
		Beowawe	2,854	2,612	201	42
		Jean	3,253	2,956	239	58
Dresden/Morris	IL	Apex	3,087	2,786	255	46
		Caliente	2,914	2,613	255	46
		Beowawe	2,769	2,507	227	35
		Jean	3,169	2,851	266	51
La Salle	IL	Apex	3,060	2,831	196	33
		Caliente	2,887	2,657	196	33
		Beowawe	2,953	2,691	225	37
		Jean	3,403	3,201	181	20
Quad Cities	IL	Apex	3,003	2,759	210	33
		Caliente	2,829	2,586	210	33
		Beowawe	2,895	2,619	238	38
		Jean	3,345	3,130	195	21

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 2 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Zion	IL	Apex	3,119	2,765	279	75
		Caliente	2,946	2,591	279	75
		Beowawe	2,801	2,486	252	64
		Jean	3,201	2,829	291	81
Wolf Creek	KS	Apex	2,685	2,528	131	27
		Caliente	2,512	2,354	131	27
		Beowawe	2,368	2,249	103	16
		Jean	2,767	2,593	142	32
River Bend	LA	Apex	3,509	3,114	322	73
		Caliente	3,380	2,944	377	59
		Beowawe	3,445	2,975	406	65
		Jean	3,428	3,049	311	68
Waterford	LA	Apex	3,551	3,173	304	74
		Caliente	3,423	3,003	359	61
		Beowawe	3,487	3,033	388	66
		Jean	3,470	3,108	293	69
Yankee-Rowe	MA	Apex	4,471	3,466	823	183
		Caliente	4,298	3,292	823	183
		Beowawe	4,153	3,187	796	171
		Jean	4,553	3,530	835	188
Maine Yankee	ME	Apex	4,908	3,629	1,075	204
		Caliente	4,734	3,455	1,075	204
		Beowawe	4,590	3,350	1,048	193
		Jean	4,989	3,693	1,087	209
Big Rock Point	MI	Apex	3,835	3,299	431	105
		Caliente	3,662	3,126	431	105
		Beowawe	3,517	3,020	404	93
		Jean	3,917	3,364	443	110
D. C. Cook	MI	Apex	3,209	2,799	324	86
		Caliente	3,035	2,625	324	86
		Beowawe	2,891	2,520	297	75
		Jean	3,290	2,863	336	91
Fermi	MI	Apex	3,649	3,046	469	135
		Caliente	3,476	2,872	469	135
		Beowawe	3,332	2,767	442	123
		Jean	3,731	3,110	481	140
Prairie Island	MN	Apex	2,980	2,715	238	28
		Caliente	2,807	2,541	238	28
		Beowawe	2,663	2,436	210	16
		Jean	3,062	2,780	249	33
Brunswick	NC	Apex	4,768	3,972	724	71
		Caliente	4,594	3,799	724	71
		Beowawe	4,450	3,693	697	59
		Jean	4,849	4,037	736	76
Shearon Harris	NC	Apex	4,669	3,910	689	69
		Caliente	4,495	3,737	689	69
		Beowawe	4,351	3,631	662	58
		Jean	4,751	3,975	701	75
McGuire	NC	Apex	4,539	3,779	683	77
		Caliente	4,366	3,605	683	77
		Beowawe	4,221	3,500	656	65
		Jean	4,621	3,844	694	82
Seabrook	NH	Apex	4,755	3,567	987	201
		Caliente	4,582	3,393	987	201
		Beowawe	4,437	3,288	960	190
		Jean	4,837	3,632	999	206
FitzPatrick/Nine Mile Point	NY	Apex	4,213	3,296	728	188
		Caliente	4,039	3,123	728	188
		Beowawe	3,895	3,017	701	177
		Jean	4,294	3,361	740	193

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 3 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Davis Besse	OH	Apex	3,590	3,133	342	114
		Caliente	3,416	2,960	342	114
		Beowawe	3,272	2,854	315	103
		Jean	3,671	3,198	354	120
Perry	OH	Apex	3,692	3,131	416	145
		Caliente	3,519	2,958	416	145
		Beowawe	3,374	2,852	389	133
		Jean	3,774	3,196	428	150
Trojan	OR	Apex	2,202	1,897	244	61
		Caliente	2,031	1,871	136	23
		Beowawe	1,539	1,445	85	9
		Jean	2,121	1,833	233	56
Beaver Valley	PA	Apex	3,819	3,212	499	108
		Caliente	3,645	3,039	499	108
		Beowawe	3,501	2,933	472	96
		Jean	3,901	3,277	510	113
Limerick	PA	Apex	4,389	3,349	843	197
		Caliente	4,216	3,175	843	197
		Beowawe	4,072	3,070	816	186
		Jean	4,471	3,414	855	203
Susquehanna	PA	Apex	4,406	3,412	819	175
		Caliente	4,232	3,238	819	175
		Beowawe	4,088	3,133	791	164
		Jean	4,487	3,477	830	180
Three Mile Island	PA	Apex	4,283	3,330	767	186
		Caliente	4,110	3,157	767	186
		Beowawe	3,966	3,051	739	175
		Jean	4,365	3,395	778	191
Catawba	SC	Apex	4,537	3,756	702	77
		Caliente	4,363	3,583	702	77
		Beowawe	4,219	3,477	675	66
		Jean	4,618	3,821	714	82
H. B. Robinson	SC	Apex	4,513	3,745	688	78
		Caliente	4,339	3,572	688	78
		Beowawe	4,195	3,466	661	67
		Jean	4,594	3,810	700	83
Summer	SC	Apex	4,472	3,782	621	68
		Caliente	4,299	3,609	621	68
		Beowawe	4,154	3,503	594	57
		Jean	4,554	3,847	633	74
Sequoyah	TN	Apex	3,890	3,480	361	48
		Caliente	3,716	3,307	361	48
		Beowawe	3,572	3,201	333	37
		Jean	3,971	3,545	372	53
Watts Bar	TN	Apex	3,887	3,544	286	57
		Caliente	3,714	3,370	286	57
		Beowawe	3,569	3,265	259	46
		Jean	3,969	3,608	298	62
Comanche Peak	TX	Apex	2,890	2,639	213	38
		Caliente	2,716	2,465	213	38
		Beowawe	2,791	2,512	236	43
		Jean	2,445	2,338	101	5
South Texas	TX	Apex	3,055	2,800	206	49
		Caliente	3,228	2,973	206	49
		Beowawe	3,320	2,948	330	43
		Jean	2,973	2,735	194	44
North Anna	VA	Apex	4,521	3,669	686	165
		Caliente	4,347	3,496	686	165
		Beowawe	4,203	3,390	659	153
		Jean	4,602	3,734	698	170

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 4 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with direct rail access (continued)						
Vermont Yankee	VT	Apex	4,551	3,519	846	186
		Caliente	4,378	3,345	846	186
		Beowawe	4,233	3,240	818	175
		Jean	4,633	3,584	857	192
WPPSS[j] 2	WA	Apex	1,946	1,807	116	22
		Caliente	1,772	1,634	116	22
		Beowawe	1,565	1,490	66	9
		Jean	2,027	1,872	128	28
Commercial sites with indirect rail access						
Browns Ferry	AL	Apex	3,741	3,332	357	52
HH – 55.4 kilometers		Caliente	3,567	3,158	357	52
		Beowawe	3,423	3,053	329	41
		Jean	3,822	3,397	368	57
Diablo Canyon	CA	Apex	893	609	174	110
HH – 43.5 kilometers		Caliente	1,067	783	174	110
		Beowawe	1,157	872	203	82
		Jean	812	544	162	105
St. Lucie	FL	Apex	4,938	4,073	780	85
HH – 23.3 kilometers		Caliente	4,765	3,899	780	85
		Beowawe	4,621	3,794	753	73
		Jean	4,863	4,006	732	125
Turkey Point	FL	Apex	5,285	4,305	841	138
HH – 17.4 kilometers						
		Caliente	5,111	4,132	841	138
		Beowawe	4,967	4,026	814	126
		Jean	5,366	4,370	853	143
Calvert Cliffs	MD	Apex	4,543	3,448	881	213
HH – 41.9 kilometers		Caliente	4,369	3,275	881	213
		Beowawe	4,225	3,169	854	201
		Jean	4,625	3,513	893	218
Palisades	MI	Apex	3,257	2,816	353	88
HH – 41.9 kilometers		Caliente	3,083	2,642	353	88
		Beowawe	2,939	2,537	326	77
		Jean	3,339	2,881	365	93
Callaway	MO	Apex	2,807	2,636	140	32
HH – 18.5 kilometers		Caliente	2,634	2,462	140	32
		Beowawe	2,490	2,357	113	20
		Jean	2,889	2,701	151	37
Grand Gulf	MS	Apex	3,686	3,355	291	39
HH – 47.8 kilometers		Caliente	3,512	3,181	291	39
		Beowawe	3,368	3,076	264	28
		Jean	3,767	3,419	303	44
Cooper Station	NE	Apex	2,429	2,252	141	36
HH – 53.8 kilometers		Caliente	2,256	2,078	141	36
		Beowawe	2,111	1,973	114	25
		Jean	2,511	2,317	153	42
Fort Calhoun	NE	Apex	2,313	2,189	102	21
HH – 6.0 kilometers		Caliente	2,139	2,015	102	21
		Beowawe	1,995	1,910	75	10
		Jean	2,394	2,254	114	27
Salem/Hope Creek	NJ	Apex	4,551	3,375	946	229
HH – 51.0 kilometers		Caliente	4,378	3,202	946	229
		Beowawe	4,234	3,097	919	218
		Jean	4,633	3,440	958	235
Oyster Creek	NJ	Apex	4,568	3,395	952	221
HH – 28.5 kilometers		Caliente	4,395	3,222	952	221
		Beowawe	4,251	3,116	925	209
		Jean	4,650	3,460	964	226

Table J-12. Rail transportation distances from commercial and DOE sites to Nevada ending rail nodes[a] (kilometers)[b,c] (page 5 of 5).

Site	State	Destination	Total[d]	Rural	Suburban	Urban
Commercial sites with indirect rail access (continued)						
Peach Bottom	PA	Apex	4,304	3,335	778	190
HH – 58.9 kilometers		Caliente	4,131	3,161	778	190
		Beowawe	3,986	3,056	751	179
		Jean	4,386	3,400	790	196
Oconee	SC	Apex	4,257	3,662	534	61
HH – 17.5 kilometers		Caliente	4,084	3,488	534	61
		Beowawe	3,940	3,383	507	50
		Jean	4,339	3,726	545	66
Surry	VA	Apex	4,505	3,927	512	66
HH – 75.2 kilometers		Caliente	4,332	3,753	512	66
		Beowawe	4,188	3,648	484	55
		Jean	4,587	3,992	523	72
Kewaunee	WI	Apex	3,444	2,954	395	95
HH – 9.7 kilometers		Caliente	3,270	2,780	395	95
		Beowawe	3,126	2,675	368	84
		Jean	3,526	3,019	406	100
Point Beach	WI	Apex	3,397	2,938	370	89
HH – 36.4 kilometers		Caliente	3,224	2,765	370	89
		Beowawe	3,080	2,659	343	78
		Jean	3,479	3,003	381	94
DOE spent nuclear fuel and high-level waste (direct rail access)						
Ft. St. Vrain[g]	CO	Apex	1,561	1,453	93	14
		Caliente	1,387	1,280	93	14
		Beowawe	1,298	1,266	29	3
		Jean	1,643	1,518	105	20
INEEL[h]	ID	Apex	1,059	978	66	15
		Caliente	885	804	66	15
		Beowawe	741	699	39	4
		Jean	1,140	1,042	78	21
West Valley[i]	NY	Apex	3,972	3,169	638	165
		Caliente	3,798	2,995	638	165
		Beowawe	3,654	2,890	611	153
		Jean	4,053	3,234	650	170
Savannah River Site[h]	SC	Apex	4,374	3,690	609	75
		Caliente	4,201	3,517	609	75
		Beowawe	4,057	3,411	581	64
		Jean	4,456	3,755	620	80
Hanford Site[h]	WA	Apex	1,933	1,795	116	22
		Caliente	1,760	1,622	116	22
		Beowawe	1,553	1,477	66	9
		Jean	2,015	1,860	128	28

a. The ending rail nodes (INTERLINE computer program designations) are Apex-14763; Caliente-14770; Beowawe-14791; and Jean-16328.
b. To convert kilometers to miles, multiply by 0.62137.
c. This analysis used the INTERLINE computer program to estimate distances.
d. Totals might differ from sums due to method of calculation and rounding.
e. NP = nuclear plant.
f. DOE spent nuclear fuel.
g. DOE spent nuclear fuel and high-level radioactive waste.
h. DOE high-level radioactive waste.
i. WPPSS = Washington Public Power Supply System.

Selection of Highway Routes. The analysis of national transportation impacts used route characteristics of existing highways, such as distances, population densities, and state-level accident statistics. The analysis of highway shipments of spent nuclear fuel and high-level radioactive waste used the HIGHWAY computer model (Johnson et al. 1993a, all) to determine highway routes using regulations of the Department of Transportation (49 CFR 397.101) that specify how routes are selected. The selection of "preferred routes" is required for shipment of these materials. DOE has determined that the HIGHWAY program is appropriate for calculating highway routes and related information (Maheras and

Pippen 1995, pages 2 to 5). HIGHWAY is a routing tool that DOE has used in previous EISs [for example, the programmatic EIS on spent nuclear fuel (DOE 1995, page I-6) and the Waste Isolation Pilot Plant Supplement II EIS (DOE 1997a, pages 5 to 13)] to determine highway routes for impact analysis.

Because the regulations require that the preferred routes result in reduced time in transit, changing conditions, weather, and other factors could result in the use of more than one route at different times for shipments between the same origin and destination. However, for this analysis the program selected only one route for travel from each site to the Yucca Mountain site.

Although shipments could use more than one preferred route in national highway transportation to comply with Department of Transportation regulations (49 CFR 397.101), under current Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments (49 CFR 397.103). At this time the State of Nevada has not identified any alternative or additional preferred routes that DOE could use for shipments to the repository.

Selection of Rail Routes. Rail transportation routing of spent nuclear fuel and high-level radioactive waste shipments is not regulated by the Department of Transportation. As a consequence, the routing rules used by the INTERLINE computer program (Johnson et al. 1993b, all) assumed that railroads would select routes using historic practices. DOE has determined that the INTERLINE program is appropriate for calculating routes and related information for use in transportation analyses (Maheras and Pippen 1995, pages 2 to 5). Because the routing of rail shipments would be subject to future, possibly different practices of the involved railroads, DOE could use other rail routes.

For the 19 commercial sites that have the capability to handle and load rail casks but do not have direct rail service, DOE used the HIGHWAY computer program to identify routes for heavy-haul transportation to nearby railheads. For such routes, routing agencies in affected states would need to approve the transport and routing of overweight and overdimensional shipments.

J.1.2.2.2 *Routes for Shipping Rail Casks from Sites Not Served by a Railroad*

In addition to routes for legal-weight trucks and rail shipments, 19 commercial sites that are not served by a railroad, but that have the capability to load rail casks, could ship spent nuclear fuel to nearby railheads using heavy-haul trucks (see Table J-12). Fourteen of these sites are on navigable waterways; some of these could ship by barge to railheads. Distances to the nearest railheads for barge shipments were estimated for each of the 14 reactor sites. These distances are listed in Table J-13.

J.1.2.2.3 *Sensitivity of Analysis Results to Routing Assumptions*

Routing for shipments of spent nuclear fuel and high-level radioactive waste to the proposed repository would comply with regulations of the Department of Transportation and the Nuclear Regulatory Commission in effect at the time shipments would occur. Unless the State of Nevada designates alternative or additional preferred routes, to comply with Department of Transportation regulations all preferred routes would ultimately enter Nevada on Interstate 15 and travel to the repository on U.S. Highway 95. States can designate alternative or additional preferred routes for highway shipments. At this time the State of Nevada has not identified any alternative or additional preferred routes DOE could use for shipments to the repository. Section J.3.1.3 examines the sensitivity of transportation impacts both nationally and regionally (within Nevada) to changes in routing assumption within Nevada.

Table J-13. Barge transportation distances from sites to intermodal rail nodes (kilometers).[a,b]

Site	State	Total[d]	Rural	Suburban	Urban
Browns Ferry	AL	57	52	5	0
Diablo Canyon	CA	143	143	0	0
St. Lucie	FL	140	50	52	39
Turkey Point	FL	54	53	0	1
Calvert Cliffs	MD	99	98	2	0
Palisades	MI	256	256	0	0
Grand Gulf	MS	51	51	0	0
Cooper	NE	117	100	16	1
Salem/Hope Creek	NJ	30	30	0	0
Oyster Creek	NJ	130	77	36	17
Surry	VA	71	60	8	3
Kewaunee	WI	293	285	2	7
Point Beach	WI	301	293	2	7

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances estimated with INTERLINE (Johnson et al. 1993b, all).
c. Intermodal rail nodes selected for purpose of analysis. Source: TRW (1999a, Section 4).
d. Totals might differ from sums due to methods of calculation and rounding.

J.1.3 ANALYSIS OF IMPACTS FROM INCIDENT-FREE TRANSPORTATION

DOE analyzed the impacts of incident-free transportation for shipments of commercial and DOE spent nuclear fuel and DOE high-level radioactive waste that would be shipped under the Proposed Action and Inventory Modules 1 and 2 from 77 sites to the repository. The analysis estimated impacts to the public and workers and included impacts of loading shipping casks at commercial and DOE sites and other preparations for shipment as well as intermodal transfers of casks from heavy-haul trucks or barges to rail cars.

J.1.3.1 Methods and Approach for Analysis of Impacts for Loading Operations

The analysis used methods and assessments developed for spent nuclear fuel loading operations at commercial sites to estimate radiological impacts to involved workers at commercial and DOE sites. Previously developed conceptual radiation shield designs for shipping casks (Schneider et al. 1987, Sections 4 and 5), rail and truck shipping cask dimensions, and estimated radiation dose rates at locations where workers would load and prepare casks (Smith, Daling, and Faletti 1992, page 4.2) for shipment were the analysis bases for loading operations. In addition, tasks and time-motion evaluations from these studies were used to describe spent nuclear fuel handling and loading. These earlier evaluations were based on normal, incident-free operations that would be conducted according to Nuclear Regulatory Commission regulations that establish radiation protection criteria for workers.

The analysis assumed that noninvolved workers would not have tasks that would result in radiation exposure. In a similar manner, the analysis projected that the dose to the public from loading operations would be extremely small, resulting in no or small impacts. A separate evaluation of the potential radiation dose to members of the public from loading operations at commercial nuclear reactor facilities showed that the dose would be very low, less than 0.001 person-rem per metric ton uranium of spent nuclear fuel loaded (DOE 1986, page 2.42, Figure 2.9). Public doses from activities at commercial and DOE sites generally come from exposure to airborne emissions and, in some cases, waterborne effluents containing low levels of radionuclides. However, direct radiation at publicly accessible locations near these sites typically is not measurable and contributes negligibly to public dose and radiological impacts. Though DOE expects no releases from loading operations, this analysis estimated that the dose to the public would be 0.001 person-rem per metric ton uranium, and metric ton equivalents, for DOE spent nuclear fuel and high-level radioactive waste. Noninvolved workers could also be exposed to low levels of radioactive materials and radioactivity from loadout operations. However, because these workers would not work in radiation areas they would receive a very small fraction of the dose received by involved workers. DOE anticipates that noninvolved workers would receive individual doses similar to those received by members of the public. Because the population of noninvolved workers would be small compared to the population of the general public near the 77 sites, the dose to these workers would be a small fraction of the public dose.

The analysis used several basic assumptions to evaluate impacts from loading operations at DOE sites:

- Operations to load spent nuclear fuel and high-level radioactive waste at DOE facilities would be similar to loading operations at commercial facilities.

- Commercial spent nuclear fuel would be in storage pools or in dry storage at the reactors and DOE spent nuclear fuel would be in dry storage, ready to be loaded directly in Nuclear Regulatory Commission-certified shipping casks and then on transportation vehicles. In addition, DOE high-level radioactive waste could be loaded directly in casks. All preparatory activities, including packaging, repackaging, and validating the acceptability of spent nuclear fuel for acceptance at the repository would be complete prior to loading operations.

- Commercial spent nuclear fuel to be placed in the shipping casks would be uncanistered or canistered fuel assemblies, with at least one assembly in a canister. DOE spent nuclear fuel and high-level radioactive waste would be in disposable canisters. Typically, uncanistered assemblies would be loaded into shipping casks under water in storage pools (wet storage). Canistered spent nuclear fuel could be loaded in casks directly from dry storage facilities or storage pools.

In addition, because handling and loading operations for DOE spent nuclear fuel and high-level radioactive waste and commercial spent nuclear fuel would be similar, the analysis assumed that impacts to workers during the loading of commercial spent nuclear fuel could represent those for the DOE materials, even though the radionuclide inventory of commercial fuel and the resultant external dose rate would be higher than those of the DOE materials. This conservative assumption of selecting impacts from commercial handling and loading operations overestimated the impacts of DOE loading operations, but it enabled the use of detailed real information developed for commercial loading operations to assess impacts for DOE operations. Equivalent information was not available for operations at DOE facilities. To gauge the conservatism of the assumption DOE compared the radioactivity of contents of shipments of commercial and DOE spent nuclear fuel and high-level radioactive waste. Table J-14 compares typical inventories of important contributors to the assessment of worker and public health impacts. These are cesium-137 and actinide isotopes (including plutonium) for rail shipments of commercial spent nuclear fuel, DOE spent nuclear fuel, and DOE high-level radioactive waste. Although other factors are also important (for example, material form and composition), these indicators provide an index of the relative hazard potential of the materials. Appendix A contains additional information on the radionuclide inventory and characteristics of spent nuclear fuel and high-level radioactive waste.

J.1.3.1.1 *Radiological Impacts of Loading Operations at Commercial Sites*

In 1987, DOE published a study of the estimated radiation doses to the public and workers resulting from the transport of spent nuclear fuel from commercial nuclear power reactors to a hypothetical deep geologic repository (Schneider et al. 1987, all). This study was based on a single set of spent nuclear fuel characteristics and a single split [30 percent/70 percent by weight; 900 metric tons uranium/2,100 metric tons uranium per year] between truck and rail conveyances. DOE published its findings on additional radiological impacts on monitored retrievable storage workers in an addendum to the 1987 report (Smith, Daling, and Faletti 1992, all). The technical approaches and impacts summarized in these DOE reports

Table J-14. Typical cesium-137, actinide isotope, and total radioactive material content (curies) in a rail shipping cask.[a]

Material	Cesium-137	Actinides (excluding uranium)[b]	Total
Commercial spent nuclear fuel	810,000	650,000	2,000,000
High-level radioactive waste	120,000	40,000[c]	280,000
DOE spent nuclear fuel (except naval spent nuclear fuel)	260,000	160,000	620,000
Naval spent nuclear fuel	550,000	30,000	1,200,000

a. Source: Appendix A. Source estimated based on 36 typical pressurized-water reactor fuel assemblies for commercial spent nuclear fuel; one dual-purpose shipping canister for naval spent fuel; five canisters of DOE spent nuclear fuel; and five canisters of high-level radioactive waste.

b. Uranium would not be an important contributor to health and safety risk.

c. Includes plutonium can-in-canister with high-level radioactive waste.

were used to project involved worker impacts that would result from commercial at-reactor spent nuclear fuel loading operations. DOE did not provide a separate analysis of noninvolved worker impacts in these reports. For the analysis in this EIS, DOE assumed that noninvolved workers would not receive radiation exposures from loading operations. This assumption is appropriate because noninvolved workers would be personnel with managerial or administrative support functions directly related to the loading tasks but at locations, typically in offices, away from areas where loading activities took place.

In the DOE study, worker impacts from loading operations were estimated for a light-water reactor with pool storage of spent nuclear fuel. The radiological characteristics of the spent nuclear fuel in the analysis was 10-year-old, pressurized-water reactor fuel with an exposure history (burnup) of 35,000 megawatt-days per metric ton. In addition, the reference pressurized-water reactor and boiling-water reactor fuel assemblies were assumed to contain 0.46 and 0.19 MTU, respectively, prior to reactor irradiation. These parameters for spent nuclear fuel are similar to those presented in Appendix A of this EIS. The use of the parameters for spent nuclear fuel presented in Appendix A would be likely to lead to similar results.

In the 1987 study, radiation shielding analyses were done to provide information on (1) the conceptual configuration of postulated reference rail and truck transportation casks, and (2) the direct radiation levels at accessible locations near loaded transportation casks. The study also presented the results of a detailed time-motion analysis of work tasks that used a loading concept of operations. This task analysis was coupled with cask and at-reactor direct radiation exposure rates to estimate radiation doses to involved workers (that is, those who would participate directly in the handling and loading of the transportation casks and conveyances). Impacts to members of the public from loading operations had been shown to be small [fraction of a person-millirem population dose; (Schneider et al. 1987, page 2.9)] and were eliminated from further analysis in the 1987 report. The at-reactor-loading concept of operations included the following activities:

1. Receiving the empty transportation cask at the site fence

2. Preparing and moving the cask into the facility loading area

3. Removing the cask from the site prime mover trailer

4. Preparing the cask for loading and placing it in the water-filled loading pit

5. Transferring spent nuclear fuel from its pool storage location to the cask

6. Removing the cask from the pool and preparing it for shipment

7. Placing the cask on the site prime mover trailer

8. Moving the loaded cask to the site fence where the trailer is connected to the transportation carrier's prime mover for offsite shipment

The results for loading operations are listed in Table J-15.

Table J-15. Principal logistics bases and results for the reference at-reactor loading operations.[a]

Parameter	Conveyance		
	Rail[b]	Truck[c]	Total
Annual loading rate (MTU/year)[d]	2,100	900	3,000
Transportation cask capacity, PWR - BWR (MTU/cask)	6.5/6.70	0.92/0.93	NA[e]
Annual shipment rate (shipments/year)	320	970	1,290
Average loading duration,[f] PWR - BWR (days)	2.3/2.5	1.3/1.4	NA
Involved worker specific CD,[g] PWR - BWR (person-rem/MTU)	0.06/0.077	0.29/0.31	NA

a. Source: Schneider et al. (1987, pages 2.5 and 2.7).
b. 14 pressurized-waste reactor and boiling-water reactor spent nuclear fuel assemblies per rail transportation cask.
c. 2 pressurized-waste reactor and boiling-water reactor spent nuclear fuel assemblies per truck transportation cask.
d. MTU = metric tons of uranium.
e. NA = not applicable.
f. Based on single shift operations; carrier drop-off and pick-up delays were not included.
g. Collective dose expressed as the sum of the doses accumulated by all loading (involved) workers, regardless of the total number of workers assigned to loading tasks.

The loading activities that the study determined would produce the highest collective unit impacts are listed in Table J-16. As listed in this table, the involved worker collective radiation doses would be dominated by tasks in which the workers would be near the transportation cask when it contained spent nuclear fuel, particularly when they were working around the cask lid area. These activities would deliver at least 40 percent of the total collective worker doses. Worker impacts from the next largest dose-producing tasks (working to secure the transportation cask on the trailer) would account for 12 to 19 percent of the total impact. The impacts are based on using crews of 13 workers [the number of workers assumed in the Schneider et al. (1987, Section 2) study] dedicated solely to performing cask-handling work. The involved worker collective dose was calculated using the following formula:

$$\text{Collective dose (person-rem)} = A \times B \times C \times D \times E$$

where: A = number of pressurized-water or boiling-water reactor spent nuclear fuel shipments being analyzed under each transportation scenario (from Tables J-5 and J-6)

B = number of transportation casks included in a shipment (set at 1 for both transportation scenarios)

C = number of pressurized-water or boiling-water reactor spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation, expressed as metric tons uranium per assembly (from Table J-15)

E = involved worker-specific collective dose in person-rem/metric ton uranium for each fuel type (from Table J-15)

Table J-16. At-reactor reference loading operations—collective impacts to involved workers.[a]

Task description	Rail CD/MTU[b] (PWR - BWR)[c]	Rail Percent of total impact	Truck CD/MTU (PWR - BWR)	Truck Percent of total impact
Install cask lids; flush cask interior; drain, dry and seal cask	0.025/0.024	40/31	0.126/0.126	43/40
Install cask binders, impact limiters, personnel barriers	0.010/0.009	15/12	0.056/0.055	19/18
Load SNF into cask	0.011/0.027	17/35	0.011/0.027	4/9
On-vehicle cask radiological decontamination and survey	0.003/0.003	5/4	0.018/0.018	6/6
Final inspection and radiation surveys	0.002/0.002	4/3	0.016/0.015	5/5
All other (19) activities	0.011/0.012	19/16	0.066/0.073	23/23
Task totals	**0.062/0.077**	**100/100**	**0.29/0.31**	**100/100**

a. Source: Schneider et al. (1987, page 2.9).
b. CD/MTU = Collective dose (person-rem effective dose equivalent) per metric ton uranium. The at-reactor loading
c. crew size is 13 involved workers.
d. PWR = pressurized-water reactor; BWR = boiling-water reactor.

Because worker doses are linked directly to the number of loading operations performed, the highest average individual doses under each transportation scenario would occur at the reactor sites having the most number of shipments. Accordingly, the average individual dose impacts were calculated for the limiting site using the equation:

$$\text{Average individual dose (rem per involved worker)} = (A \times B \times C \times D \times E) \div F$$

where: A = largest value for the number of shipments from a site under each transportation scenario (from Tables J-5 and J-6)

B = number of transportation casks included in a shipment (set at 1 for both transportation options)

C = number of spent nuclear fuel assemblies in a transportation cask (from Table J-3)

D = amount of uranium in the spent nuclear fuel assembly prior to reactor irradiation in metric tons uranium per assembly (from Table J-15)

E = involved worker-specific collective dose in person-rem per metric ton uranium for each fuel type (from Table J-15)

F = involved worker crew size (set at 13 persons for both transportation options; from Table J-16)

J.1.3.1.2 *Radiological Impacts of DOE Spent Nuclear Fuel and High-Level Radioactive Waste Loading Operations*

The methodology used to estimate impacts to workers during loading operations for commercial spent nuclear fuel was also used to estimate impacts of loading operations for DOE spent nuclear fuel and high-level radioactive waste. The exposure factor for loading boiling-water reactor spent nuclear fuel in truck casks at commercial facilities (person-rem per MTU) was used (see Table J-16). The exposure factor for truck shipments of boiling-water reactor spent nuclear fuel was based on a cask capacity of five boiling-water reactor spent nuclear fuel assemblies (about 0.9 MTHM). The analysis used this factor because it would result in the largest estimates for dose per operation.

J.1.3.2 Methods and Approach for Analysis of Impacts from Incident-Free Transportation

The potential exists for human health impacts to workers and members of the public from incident-free transportation of spent nuclear fuel and high level radioactive waste. *Incident-free* transportation means normal accident-free shipment operations during which traffic accidents and accidents in which radioactive materials could be released do not occur; these are addressed separately in Section J.1.4. Incident-free impacts could occur from exposure to (1) external radiation in the vicinity of the transportation casks, or (2) transportation vehicle emissions, both during normal transportation.

J.1.3.2.1 *Incident-Free Radiation Dose to Populations*

The analysis used the RADTRAN4 computer program (Neuhauser and Kanipe 1992, all) to evaluate incident-free impacts for populations. The RADTRAN4 input parameters used to estimate incident-free impacts are listed in Table J-17. Through extensive review (Maheras and Pippen 1995, Section 3 and 4), DOE has determined that this program provides valid estimates of population doses for use in the evaluation of risks of transporting radioactive materials, including spent nuclear fuel and high-level radioactive waste. DOE has used the RADTRAN4 code to analyze transportation impacts for other environmental impact statements (for example, DOE 1995, Appendix E; DOE 1997b, Appendixes F and G). The program used population densities from 1990 census data to calculate the collective dose to populations that live along transportation routes [within 800 meters (0.5 mile) of either side of the route]. Table J-18 lists the estimated number of people who live within 800 meters of national routes.

The analysis used five kinds of information to estimate collective doses to populations:

- External radiation dose rate around shipping casks
- Number of people who would live within 800 meters (0.5 mile) along the routes of travel
- Distances individuals would live from the routes
- Amount of time each individual would be exposed as a shipment passed by
- Number of shipments that would be transported over each route

The first four were developed using the data listed in Table J-19. The fifth kind of information (the number of shipments that would use a transportation route) was developed with the use of the CALVIN computer program discussed in Section J.1.1.1, the DOE Throughput Study (TRW 1997, Section 6.1.1), data on DOE spent nuclear fuel and high-level radioactive waste inventories in Appendix A, and data from DOE sites (Jensen 1998, all). The analysis used CALVIN to estimate the number of shipments from each commercial site. The Throughput Study provided the estimated number of shipments of high-level radioactive waste from the four DOE sites. Information provided by the DOE National Spent Nuclear Fuel Program (Jensen 1998, all) and in Appendix A was used to estimate shipments of DOE spent nuclear fuel.

The analysis used a value of 10 millirem per hour at a distance of 2 meters (6.6 feet) from the side of a transport vehicle for the external dose rate around shipping casks. This value is the maximum allowed by regulations of the Department of Transportation for shipments of radioactive materials [49 CFR 173.441(b)]. Dose rates at distances greater than 2 meters from the side of a vehicle would be less. The dose rate at 30 meters (100 feet) from the vehicle would be less than 0.2 millirem per hour; at a distance of 800 meters (2,625 feet) the dose rate would be less than 0.0002 millirem per hour.

Table J-17. Input parameters and parameter values used for the incident-free national truck and rail transportation analysis.

Parameter	Legal-weight truck transportation	Rail transportation	Legal-weight truck and rail
Package type			Type B shipping cask
Package dimension			4.77 meters[a] long
Dose rate			10 millirem per hour, 2 meters from side of vehicle
Number of crewmen	2	5	
Distance from source to crew	3 meters	152 meters	
Speed			
Rural	88 km[b] per hour	64 km per hour	
Suburban			40 km per hour
Urban			24 km per hour
Stop time per km	0.011 hours per km	0.033 hours per km[c]	
Number of people exposed while stopped	50	Based on suburban population density	
Number of people per vehicle sharing route	2	3	
Population densities (persons per km²)[d]			
Rural			(e)
Suburban			(e)
Urban			(e)
One-way traffic count (vehicles per hour)			
Rural	470	1	
Suburban	780	5	
Urban	2,800	5	

a. To convert meters to feet, multiply by 3.2808.
b. To convert kilometers (km) to miles, multiply by 0.62137.
c. Assumes general freight rather than dedicated service.
d. To convert square kilometers to square miles, multiply by 0.3861.
e. Population densities along transportation routes were estimated using the HIGHWAY and INTERLINE computer programs. These programs used 1990 Census data.

Table J-18. Population within 800 meters (0.5 mile) of routes for incident-free transportation using 1990 census data.

Transportation scenario	1990 Census data
Mostly legal-weight truck	7,200,000
Mostly rail	11,100,000

a. Source: TRW (1999a, pages 18 and 19).

The second kind of information used in the analysis was the number of people who potentially would be close enough to shipments to be exposed to radiation from the casks. The analysis determined the estimated offlink number of people [those within the 1.6-kilometer (1-mile) region of influence] by multiplying the population densities (persons per square kilometer) in population zones through which a route would pass by the 1.6-kilometer width of the region of influence and by the length of the route through the population zones. Onlink populations (those sharing the route and people at stops along the route) were estimated using assumptions from other EISs that have evaluated transportation impacts (DOE 1995, Appendix I; DOE 1996a, Appendix E; DOE 1997b, Appendixes F and G). The travel distance in each population zone was determined for legal-weight truck shipments by using the HIGHWAY computer program (Johnson et al. 1993a, all) and for rail shipments by using the

Table J-19. Information used for analysis of incident-free transportation impacts.

Population zones	Population within 800 meters[a] (per kilometer of route)	Travel speed (kilometers per hour) Legal-weight truck	Heavy-haul truck	Rail	Dose rate 2 meters[b] from vehicle (millirem per hour)
Urban	(c)	24	24	24[d]	10
Suburban	(c)	40[d]	40	40	10
Rural	(c)	88	40	64	10

a. 800 meters = about 2,600 feet.
b. 2 meters = about 6.6 feet.
c. Estimates of population within 800 meters of a route are based on analysis of census block data using HIGHWAY (Johnson et al. 1993a, all) and INTERLINE (Johnson et al. 1993b, all) computer programs. The analysis used actual populations along routes based on the 1990 Census.
d. Analysis of impacts for shipments of naval spent nuclear fuel used 40 kilometers (25 miles) per hour for heavy-haul truck speed and 24 kilometers (15 miles) per hour for train speed in urban, suburban, and rural zones.

INTERLINE program (Johnson et al. 1993b, all). These programs used 1990 census block group data to identify where highways and railroads enter and exit each type of population zone, which the analysis used to determine the total lengths of the highways and railroads in each population zone.

The third kind of information—the distances individuals live from the route used in the analysis—is the estimated the number of people who live within 800 meters (about 2,600 feet) of the route. The analysis assumed that population density is uniform in population zones.

The determination of the fourth kind of information used in the analysis—the time that people could be exposed as shipments passed—was based on the assumed travel speed of shipments in each population zone along the route. For example, travel at 24 kilometers (15 miles) an hour in urban areas would lead to a longer exposure time than travel at 88 kilometers (55 miles) an hour in rural areas. Persons in vehicles traveling along a route with a shipment of spent nuclear fuel or high-level radioactive waste or persons who lived near railyards where shipments would be switched between trains could be exposed for longer periods.

With the five kinds of information, the analysis used RADTRAN4 to calculate exposures for the following groups:

- *Public along the route (Offlink Exposure):* Collective doses for persons living or working within 0.8 kilometer (0.5 mile) on each side of the transportation route.

- *Public sharing the route (Onlink Exposure):* Collective doses for persons in vehicles sharing the transportation route; this includes persons traveling in the same or opposite direction and those in vehicles passing the shipment.

- *Public during stops (Stops):* Collective doses for people who could be exposed while a shipment was stopped en route. For truck transportation, these would include stops for refueling, food, and rest. For rail transportation, stops would occur in railyards along the route to switch railcars from inbound trains to outbound trains traveling toward the Yucca Mountain site, and to change train crews and equipment (locomotives).

- *Worker exposure (Occupational Exposure):* Collective doses for truck and rail transportation crew members.

- *Security escort exposure (Occupational Exposure):* Collective doses for security escorts. In calculating doses to workers the analysis conservatively assumed that the maximum number of escorts required by regulations (10 CFR 73.37) would be present for urban, suburban, and rural population zones.

The sum of the doses for the first three categories is the total nonoccupational (public) dose.

Unit dose factors were used to calculate collective dose. These factors, which are listed in Table J-20, represent the dose that would be received by a population of 1 person per square kilometer for one shipment of radioactive material moving a distance of 1 kilometer (0.62 mile) in the indicated population density zone. The unit dose factors for incident-free transportation reflect the assumption that the dose rate external to shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by Department of Transportation regulations—10 millirem per hour at 2 meters (6 feet) from the side of the transport vehicle (49 CFR 173.441). The incident-free dose from transporting a single shipment was determined by multiplying the appropriate unit dose factors by corresponding distances in each of the population zones the shipment route passes through and the population density of the zone. The collective dose from all shipments from a site were determined by multiplying the dose from a single shipment by the number of shipments that would be required to transport the site's spent nuclear fuel or high-level radioactive waste to the repository. Collective dose was converted to the estimated number of latent cancer fatalities using conversion factors recommended by the International Commission on Radiological Protection (ICRP 1991, page 22). These values are 0.0004 for radiation workers and 0.0005 for the general population.

Table J-20. Unit dose factors for incident-free national truck and rail transportation of spent nuclear fuel and high-level radioactive waste.

		Unit dose factors (person-rem per kilometer)[a]		
Mode	Exposure group	Rural	Suburban	Urban
Truck	*Involved worker*	4.56×10^{-5}	1×10^{-4}	1.67×10^{-4}
	Public			
	Offlink[b]	3.2×10^{-8}	3.52×10^{-8}	4.33×10^{-8}
	Onlink[c]	7.81×10^{-6}	2.25×10^{-5}	2.32×10^{-4}
	Stops	1.87×10^{-4}	1.87×10^{-4}	1.87×10^{-4}
Rail	*Involved worker*[d]	1.22×10^{-5}	1.22×10^{-5}	1.22×10^{-5}
	Public			
	Offlink	4.38×10^{-8}	7.02×10^{-8}	1.17×10^{-7}
	Onlink	1.03×10^{-7}	1.32×10^{-6}	3.65×10^{-6}
	Stops[e]	7.42×10^{-6}	7.42×10^{-6}	7.42×10^{-6}

a. The methodology, equations, and data used to develop the unit dose factors are discussed in Madsen et al. (1986, all) and Neuhauser and Kanipe (1992, page 4-15). Cashwell et al. (1986, page 44) contains a detailed explanation of the use of unit factors.
b. Offlink general population included persons within 800 meters (2,625 feet) of the road or railway.
c. Onlink general population included persons sharing the road or railway.
d. The nonlinear component of incident-free rail dose for crew workers because of railcar inspections and classifications is 0.014 person-rem per shipment. Ostmeyer (1986, all) contains a detailed explanation of the rail exposure model.
e. The nonlinear component of incident-free rail dose for the general population because of railcar inspections and classifications is 0.0014 person-rem per shipment. Ostmeyer (1986, all) contains a detailed explanation of the rail exposure model.

J.1.3.2.2 *Methods Used To Evaluate Incident-Free Impacts to Maximally Exposed Individuals.*

To estimate impacts to maximally exposed individuals, the same kinds of information as those used for population doses (except for population size) was needed. The analysis of doses to maximally exposed individuals used projected exposure times, the distance a hypothetical individual would be from a shipment, the number of times an exposure event could occur, and the assumed external radiation dose rate 2 meters (6.6 feet) from a shipment (10 millirem per hour). These analyses used the RISKIND computer program (Yuan et al. 1995, all). DOE has used RISKIND for analyses of transportation impacts in other environmental impact statements (DOE 1995, Appendix J; DOE 1996a, Appendix E; DOE 1997b, Appendix E). RISKIND provides appropriate results for analyses of incident-free transportation and transportation accidents involving radioactive materials (Maheras and Pippen 1995, Sections 5.2 and 6.2; Biwer et al. 1997, all).

The maximally exposed individual is a hypothetical person who would receive the highest dose. Because different maximally exposed individuals can be postulated for different exposure scenarios, the analysis evaluated the following exposure scenarios.

- *Crew Members.* In general, truck crew members, including security escorts and rail security escorts, would receive the highest doses during incident-free transportation (see discussion in J.1.3.2.2.1 below). The analysis assumed that the crews would be limited to a total job-related exposure of 2 rem per year (DOE 1994, Article 211).

- *Inspectors (Truck and Rail).* Inspectors would be Federal or state vehicle inspectors. On the basis of information provided by the Commercial Vehicle Safety Alliance (Battelle 1998, all; CVSA 1999, all), the analysis assumed an average exposure distance of 1 meter (3 feet) and an exposure duration of 1 hour (see discussion in J.1.3.2.2).

- *Railyard Crew Member.* For a railyard crew member working in a rail classification yard assembling trains, the analysis assumed an average exposure distance of 10 meters (33 feet) and an exposure duration of 2 hours (DOE 1997b, page E-50).

- *Resident.* The analysis assumed this maximally exposed individual is a resident who lives 30 meters (100 feet) from a point where shipments would pass. The resident would be exposed to all shipments along a particular route (DOE 1995, page I-52).

- *Individual Stuck in Traffic (Truck or Rail).* The analysis assumed that a member of the public could be 1.2 meter (4 feet) from the transport vehicle carrying a shipping cask for 1 hour. Because these circumstances would be random and unlikely to occur more than once for the same individual, the analysis assumed the individual to be exposed only once.

- *Resident near a Rail Stop.* The analysis assumed a resident who lives within 200 meters (660 feet) of a switchyard and an exposure time of 20 hours for each occurrence. The analysis of exposure for this maximally exposed individual assumes that the same resident would be exposed to all rail shipments to the repository (DOE 1995, page I-52).

- *Person at a Truck Service Station.* The analysis assumed that a member of the public (a service station attendant) would be exposed to shipments for 1 hour for each occurrence at a distance of 20 meters (70 feet). The analysis also assumed this individual would work at a location where all truck shipments would stop.

As discussed above for exposed populations, the analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.3.2.2.1 Incident-Free Radiation Doses to Inspectors. DOE estimated radiation doses to the state inspectors who would inspect shipments of spent nuclear fuel and high-level radioactive waste originating in, passing through, or entering a state. For legal-weight truck and railcar shipments, the analysis assumed that:

- Each inspection would involve one individual working for 1 hour at a distance of 2 meters (6.6 feet) from a shipping cask.
- The radiation field surrounding the cask would be the maximum permitted by regulations of the Department of Transportation (49 CFR 173.441).
- There would be no shielding between an inspector and a cask.

For rail shipments, the analysis assumed that:

- There would be a minimum of two inspections per trip—one at origin and one at destination—with additional inspections in route occurring about once every 500 kilometers (300 miles) of railcar travel.
- Rail crews would conduct the remaining along-the-route inspections.

For legal-weight truck shipments, the analysis assumed that:

- On average, state officials would conduct two inspections during each trip – one at the origin and one at the destination.
- The inspectors would use the Enhanced North American Uniform Inspection Procedures and Out-of-Service Criteria for Commercial Highway Vehicles Transporting Transuranics, Spent Nuclear Fuel, and High-Level Radioactive Waste (CVSA 1999, all).
- The shipments would receive a Commercial Vehicle Safety Alliance inspection sticker on passing inspection and before departing from the 77sites.
- Display of such a sticker would provide sufficient evidence to state authorities along a route that a shipment complied with Department of Transportation regulations (unless there was contradictory evidence), and there would be no need for additional inspections.

The analysis determined doses to state inspectors in two ways. For rail shipments, inspector doses were based on the equations and assumptions used in the RADTRAN4 computer program. The program uses an empirically derived equation that is based on observations of rail classification yard operations, as follows:

$$\text{Dose} = K_0 \times \text{dose rate} \times \text{casks per shipment} \times \text{number of shipments} \times 0.\ 16 \times 0.001$$

where:

dose	=	rem of exposure to an inspector

K_0	=	a shape factor for the cask assumed for purposes of analysis (meters); 6 meters for rail cask that would ship spent nuclear fuel
dose rate	=	the dose rate in millirem per hour 1 meter from the surface of the cask; set to 14 millirem per hour for the analysis
casks per shipment	=	the average number of casks (one cask per railcar) in a train; set to 1 for the analysis
number of shipments	=	number of shipments inspected (set to 1 for the analysis)
0.16	=	exposure factor that translates the product of cask dose rate and shape factor into inspector dose (meters per hour)
0.001	=	conversion factor to convert millirem per hour to rem per hour.

The equation shows that the calculated value for whole-body dose to an individual inspector for one inspection would be 13.4 millirem. An inspector in Nevada who inspected all rail shipments under the mostly rail scenario would receive a whole body dose of $470 \times 13.4 = 6.3$ rem in a year. If the same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to 150 rem. Using the dose to risk conversion factors published by the International Commission on Radiation Protection, this exposure would increase the likelihood of the inspector incurring a fatal cancer. This would add 6 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 23 percent (ACS 1998, page 10) to 29 percent.

For shipments by legal-weight truck, the analysis used the RISKIND computer program to estimate doses to inspectors (Yuan et al. 1995, all). The data used by the code to calculate dose includes the estimated value for dose rate at 1 meter (3.3 feet) from a cask surface, the length and diameter of the cask, the distance between the location of the individual and the cask surface, and the estimated time of exposure. For this calculation, the analysis assumed that an inspector following Commercial Vehicle Safety Alliance procedures (CVSA 1999, all) would work for 1 hour at an average distance of 2 meters (6.6 feet) from the cask. The analysis assumed that a typical legal-weight truck cask would be about 1 meter in diameter and about 5 meters (16 feet) long and that the dose rate 1 meter from the cask surface would be 14 millirem per hour. A dose rate of 14 millirem per hour 1 meter from the surface of a truck cask is approximately equivalent to the maximum dose rate allowed by Department of Transportation regulations for exclusive-use shipments of radioactive materials (49 CFR 173.441).

Using this data, the RISKIND computer code calculated an expected dose of 18 millirem for an individual inspector. Under the mostly legal-weight truck scenario in which approximately 2,100 legal-weight truck shipments would arrive in Nevada annually, a Nevada inspector working 1,800 hours per year could inspect as many as 470 shipments in a year. This inspector would receive a whole-body dose of 8.5 rem. If this same inspector inspected all shipments over the 24 years of the Proposed Action, he or she would be exposed to 204 rem. Using the dose to risk conversion factors published by the International Commission on Radiation Protection, this exposure would increase the likelihood of this individual contracting a fatal cancer. This would add about 8 percent to the likelihood for fatal cancers from all other causes, increasing the likelihood from approximately 22 percent (ACS 1998, page 10) to 32 percent.

Under the mostly legal-weight truck scenario, the annual committed dose to inspectors in a state that inspected all incoming legal-weight truck shipments containing spent nuclear fuel or high-level radioactive waste would be about 38 person-rem. Over 24 years, the population dose for these inspectors would be about 910 person-rem. This would result in about 0.34 latent cancer fatality (this is equivalent to a 36-percent likelihood that there would be 1 additional latent cancer fatality among the exposed group).

DOE implements radiation protection programs at its facilities where there is the potential for worker exposure to cumulative doses from ionizing radiation. The Department anticipates that the potential for individual whole-body doses such as those reported above would lead an involved state to implement such a radiation protection program. If similar to those for DOE facilities, the administrative control limit on individual dose would not exceed 2 rem per year (DOE 1994, Article 211) and the expected maximum exposure for inspectors would be less than 500 millirem per year.

J.1.3.2.2.2 Incident-Free Radiation Doses to Escorts. Transporting spent nuclear fuel to the Yucca Mountain site would require the use of physical security and other escorts for the shipments. Regulations (10 CFR 73.37) require escorts for highway and rail shipments. These regulations require two escorts (individuals) for truck shipments traveling in highly populated (urban) areas. One of the escorts must be in a vehicle that is separate from the shipment vehicle. For rail shipments in urban areas, at least two escorts must maintain visual surveillance of a shipment from a railcar that accompanies a cask car.

In areas that are not highly populated (suburban and rural), one escort must accompany truck shipments. The escort can ride in the cab of the shipment vehicle. At least one escort is required for rail shipments in suburban and rural areas. However, for rail shipments, the escort must occupy a railcar that is separate from the cask car and must maintain visual surveillance of the shipment at all times.

For legal-weight truck shipments, the analysis assumed that a second driver, who would be a member of the vehicle crew, would serve as an escort in all areas. The analysis assigned a second escort for travel in urban areas and assumed that this escort would occupy a vehicle that followed or led the transport vehicle by at least 60 meters (about 200 feet). The analysis assumed that the dose rate at a location 2 meters (6.6 feet) behind the vehicle would be 10 millirem per hour, which is the limit allowed by Department of Transportation regulations (49 CFR 173.441). Using this information, the analysis used the RISKIND computer program to calculate a value of approximately 0.11 millirem per hour for the dose rate 60 meters behind the transport vehicle; this is the estimated value for the dose rate in a following escort vehicle. The value for the dose rate in an escort vehicle that preceded a shipment would be lower. Because the dose rate in the occupied crew area of the transport vehicle would be less than 2 millirem per hour, the dose rate 2 meters in front of the vehicle would be much less than 10 millirem per hour, the value assumed for a location 2 meters behind the vehicle. The value of 2 millirem per hour in normally occupied areas of transport vehicles is the maximum allowed by Department of Transportation regulations (49 CFR 173.441).

To calculate the dose to escorts, the analysis assumed that escorts in separate vehicles would be required in urban areas as shipments traveled to the Yucca Mountain site. The calculations used the RISKIND computer program (Yuan et al. 1995, all); the distance of travel in urban areas provided by the HIGHWAY and INTERLINE computer codes; and the estimated speed of travel in urban areas based on data in Table J-19 to estimate the total dose to escorts. For example, truck shipments could be escorted through an average of five urban areas on average for 30 minutes in each. Using these assumptions and the estimated dose rate in an escort vehicle, the estimated dose for escorts in separate vehicles is 0.28 millirem per shipment (0.28 millirem = 5 areas per shipment × 0.5 hour per area × 0.11 millirem per hour). For the 24 years of the Proposed Action, the total dose to escorts in separate vehicles would, therefore, be about 14 rem (0.28 millirem per shipment × 50,000 shipments). This dose would lead to 0.02 latent cancer fatality in the population of escorts who would be affected.

For rail shipments, the analysis assumed that escorts would be 30 meters (98 feet) away from the end of the shipping cask on the nearest railcar. This separation distance is the sum of the:

- Length of a buffer car [about 15 meters (49 feet)] between a cask car and an escort car required by Department of Transportation regulations (49 CFR 174.89),
- Normal separation between cars [a total of about 2 meters (6.6 feet) for two separations],
- Distance from the end of a cask to the end of its rail car [about 5 meters (16 feet)], and
- Assumed average distance from the escort car's near-end to its occupants [5 to 10 meters (16 to 32 feet)].

This analysis assumed that the dose rate at 2 meters (6.6 feet) from the end of the cask car would be 10 millirem per hour, the maximum allowed by Department of Transportation regulations (49 CFR 173.441). The analysis used these assumptions and the RISKIND computer program to estimate 0.46 millirem per hour as the dose rate in the occupied areas of the escort railcar. For example, an individual escort who occupied the escort car continuously for a 5-day cross-country trip would receive a maximum dose of about 55 millirem. Escorting 26 shipments in a year, this individual would receive a maximum dose of 1.4 rem. Over the 24 years of the Proposed Action, if the same individual escorted 26 shipments every year, he or she would receive a dose of about 34 rem. Using the dose-to-risk conversion factors recommended by the International Commission on Radiation Protection (ICRP 1991, page 22), this dose would increase the potential for the individual to contract a fatal cancer from about 22 percent (ACS 1998, page 10) to 24 percent.

J.1.3.2.3 *Vehicle Emission Impacts*

Human health impacts from exposures to vehicle exhaust depend principally on the distance traveled in an urban population zone and on the impact factors for particulates and sulfur dioxide from truck (including escort vehicles) or rail emissions, fugitive dust generation, and tire abrasion (DOE 1995, page I-52).

The analysis estimated incident-free impacts from nonradiological causes using unit risk factors that account for both fatalities associated with the emissions of pollution in urban, suburban, and rural areas by transportation vehicles, including escort vehicles. Because the impacts would occur equally for trucks transporting loaded or unloaded shipping casks, the analysis used round-trip distances. Escort vehicle impacts were included only for loaded shipment miles.

The analysis used impact factors for effects on urban areas of 0.00000016 fatality per urban mile traveled (0.0000001 fatality per kilometer) by trucks and 0.00000021 fatality per urban mile traveled (0.00000013 fatality per kilometer) by trains (Rao, Wilmot, and Luna 1982, all). The region of influence used in the analysis for exposure to vehicle emissions was a band between 30 and 805 meters (98 and 2,640 feet) wide on both sides of the transportation route.

In addition to unit risk factors used to estimate impacts from vehicle emissions in urban areas, an additional factor was used to estimate health effects from vehicle exhaust emissions in rural areas. Based on data in a study by the Environmental Protection Agency that addressed latent cancer consequences of vehicle exhausts, a factor of 0.000000000072 fatality per kilometer traveled was calculated for use in rural and suburban population zones (DOE 1995, page I-52).

Although the analysis estimated human health and safety impacts of transporting spent nuclear fuel and high-level radioactive waste, exhaust and other pollutants emitted by transport vehicles into the air would not measurably affect national air quality. National transportation of spent nuclear fuel and high-level radioactive waste, which would use existing highways and railroads would average 14.2 million truck kilometers per year for the mostly truck case and 3.5 million railcar kilometers per year from the mostly rail case. The national yearly average for total highway and railroad traffic is 186 billion truck kilometers and 49 billion railcar kilometers (BTS 1999, Table 3-22). Spent nuclear fuel and high-level radioactive waste transportation would represent a very small fraction of the total national highway and railroad traffic (0.008 percent of truck kilometers and 0.007 percent of rail car kilometers). In addition, the contributions to vehicle emissions in the Las Vegas air basin, where all truck shipments (an average of five per day) would travel under the mostly legal-weight truck scenario, would be small in comparison to those from other vehicle traffic in the area. The annual average daily traffic on I-15 0.3 kilometer (0.2 mile) north of the Sahara Avenue interchange is almost 200,000 vehicles (NDOT 1997, page 7), about 20 percent of which are trucks (Cerocke 1998, all). For these reasons, national transportation of spent nuclear fuel and high-level radioactive waste by truck and rail would not constitute a meaningful source of air pollution along the nation's highways and railroads.

J.1.3.2.4 *Sensitivity of Dose Rate to Characteristics of Spent Nuclear Fuel*

For this analysis, DOE assumed that the dose rate external to all shipments of spent nuclear fuel and high-level radioactive waste would be the maximum value allowed by regulations (49 CFR 173.441). However, the dose rate for actual shipments would not be the maximum value of 10 millirem per hour at 2 meters (6.6 feet) from the sides of vehicles. Administrative margins of safety that are established to compensate for limits of accuracy in instruments and methods used to measure dose rates at the time shipments are made would result in lower dose rates. In addition, the characteristics of spent nuclear fuel and high-level radioactive waste that would be loaded into casks would always be within the limit values allowed by the cask's design and its Nuclear Regulatory Commission certificate of compliance.

For example, DOE used data provided in the *GA-4 Legal-Weight Truck Cask Design Report* (General Atomics 1993, pages 5.5-18 and 5.5-19) to estimate dose rates 2 meters (6.6 feet) from transport vehicles for various characteristics of spent nuclear fuel payloads. Figure J-7 shows ranges of burnup and cooling times for spent nuclear fuel payloads for the GA-4 cask. The figure indicates the characteristics of a typical pressurized-water reactor spent nuclear fuel assembly (see Appendix A). Based on the design data for the GA-4 cask, a shipment of typical pressurized-water reactor spent nuclear fuel would result in a dose rate of about 6 millirem per hour at 2 meters from the side of the transport vehicle, or about 60 percent of the limit established by Department of Transportation regulations (49 CFR 173.441).

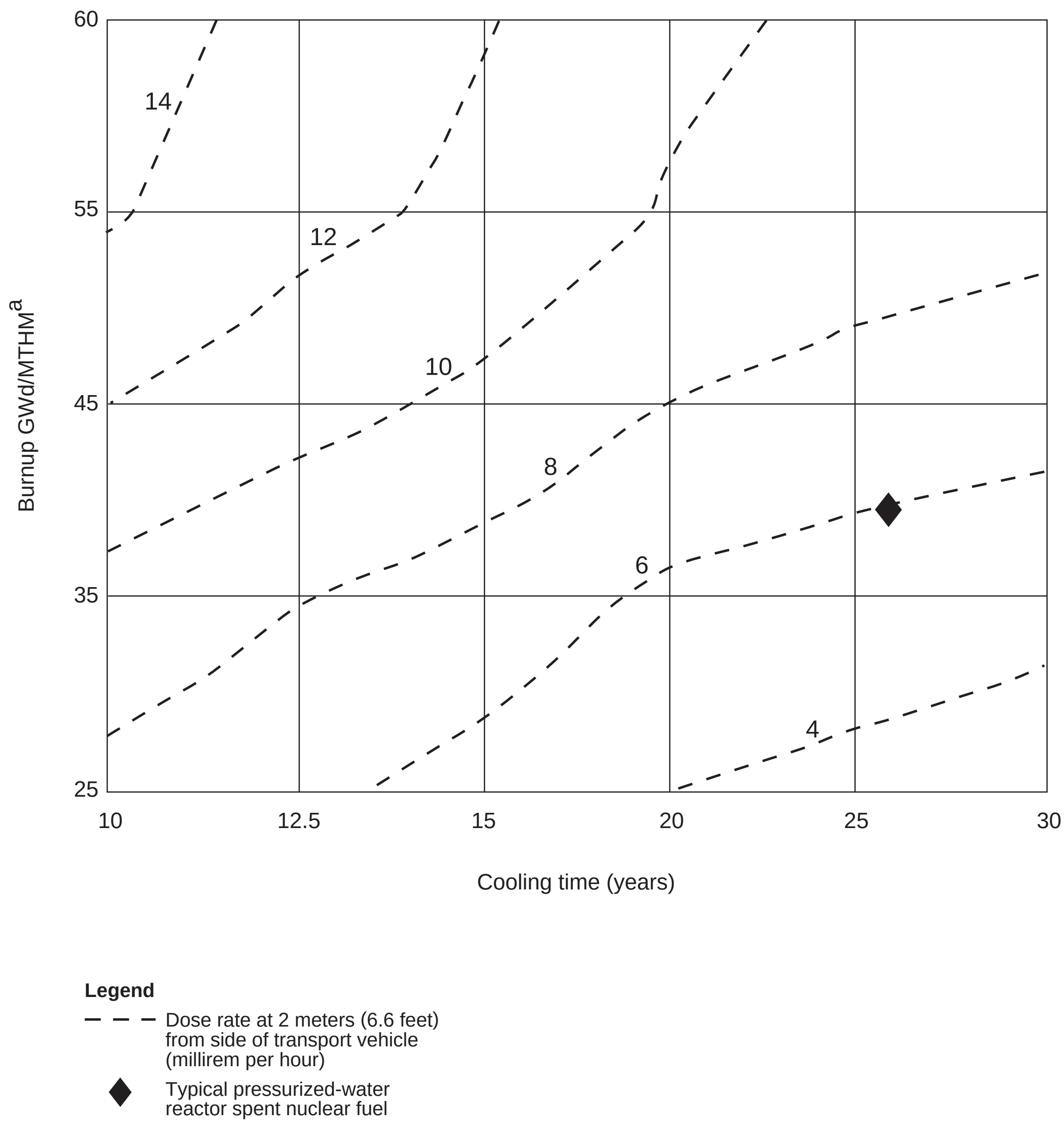
Therefore, DOE estimates that, on average, dose rates at locations 2 meters (6.6 feet) from the sides of transport vehicles would be about 50 to 70 percent of the regulatory limits. As a result, DOE expects radiological risks to workers and the public from incident-free transportation to be no more than 50 to 70 percent of the values presented in this EIS.

J.1.4 METHODS AND APPROACH TO ANALYSIS OF ACCIDENT SCENARIOS

J.1.4.1 Accidents in Loading Operations

J.1.4.1.1 *Radiological Impacts of Loading Accidents*

The analysis used information in existing reports to consider the potential for radiological impacts from accidents during spent nuclear fuel loading operations at the commercial and DOE sites. These included a report that evaluated health and safety impacts of multipurpose canister systems (TRW 1994, all) and two safety analysis reports for onsite dry storage of commercial spent nuclear fuel at independent spent fuel storage installations (PGE 1996, all; CP&L 1989, all). The latter reports address the handling and loading of spent nuclear fuel assemblies in large casks similar to large transportation casks. In addition,



a. Gigawatt days per metric ton of heavy metal.

Figure J-7. Comparison of GA-4 cask dose rate and spent nuclear fuel burnup and cooling time.

DOE environmental impact statements on the management of spent nuclear fuel and high-level radioactive waste (DOE 1995, all; DOE 1997b, all) provided information on radiological impacts from loading accidents.

TRW (1994, Sections 3.2 and 4.2) discusses potential accident scenario impacts of four cask management systems at electric utility and other spent nuclear fuel storage sites. This report concentrated on unplanned contact (bumping) during lift-handling of casks, canisters, or fuel assemblies. The two safety analysis reports for independent spent fuel storage installations for commercial spent nuclear fuel (PGE 1996, all; CP&L 1989, all) evaluated a comprehensive spectrum of accident-initiating events. These events included fires, chemical explosions, seismic events, nuclear criticality, tornado strikes and tornado-generated missile impacts, lightning strikes, volcanism, canister and basket drop, loaded shipping cask drop, and interference (bumping, binding) between the transfer cask and storage module. The DOE environmental impact statements for the interim management of spent nuclear fuel and high-level radioactive waste (DOE 1995, Appendix E; DOE 1997b, Appendixes F and G) included radiological impacts from potential accident scenarios associated with preparing, storing, and shipping these materials. These EISs do not discuss quantitative radiological impacts for accident scenarios associated with material loading, but do contain estimates of radiological impacts from accident scenarios for the spent nuclear fuel and high-level radioactive waste management activities considered. As discussed for routine loading operations, this analysis converted radiation doses to estimates of radiological impacts using dose-to-risk conversion factors of the International Commission on Radiological Protection.

J.1.4.1.2 *Industrial Safety Impacts of Loading Operations at Commercial Facilities*

The principal industrial safety impact parameters of importance to commercial industry and the Federal Government are (1) total recordable (injury and illness) cases, (2) lost workday cases associated with workplace injuries and illnesses, and (3) workplace fatalities. The frequency of these impacts under the Proposed Action and the inventory modules (Modules 1 and 2) was projected using the involved worker level of effort, expressed as the number of full-time equivalent worker multiples, that would be needed to conduct shipment tasks. The workplace loss incidence rate for each impact parameter [as shown in the DOE Computerized Accident/Incident Reporting and Recordkeeping System (CAIRS) data base (DOE 1999, all)] was used as a multiplier to convert the level of effort to expected industrial safety losses.

DOE did not explicitly analyze impacts to noninvolved workers in its earlier reports (Schneider et al. 1987, all; Smith, Daling, and Faletti 1992, all). However, for purposes of analysis in this EIS, DOE estimated that impacts to noninvolved workers would be 25 percent of the impacts to the involved workforce. This assumption is based on (1) the DOE estimate that about one of five workers assigned to a specific task would perform administrative or managerial duties, and (2) the fact that noninvolved worker loss incidence rates are generally less than those for involved workers (see Appendix F, Table F-2).

The estimated involved worker full-time equivalent multiples for each shipment scenario were estimated using the following formula:

$$\text{Involved worker full-time equivalent multiples} = (A \times B \times C \times D) \div E$$

where: A = number of shipments (from Tables J-5 and J-6)

B = average loading duration for each shipment by fuel type and conveyance mode (workdays; from Table J-15)

C = workday conversion factor = 8 hours per workday

D = involved worker crew size (13 workers; from Table J-16)

E = full-time equivalent conversion factor = 2,000 worker hours per full-time equivalent

The representative CAIRS data base loss incidence rate for each total recordable case, lost workday case, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was then multiplied by the involved worker full-time equivalent multiples to project the associated incidence. The involved worker total recordable case incidence rate used was that reported in the DOE CAIRS data base (DOE 1999, all) for the 1992 to 1997 period of record because neither the Nuclear Regulatory Commission nor the Bureau of Labor Statistics maintains data on commercial power reactor industrial safety losses. The total recordable case incidence rate, 410 cases in a workforce of 15,000 workers (0.03 total recordable case per full-time equivalent), is the averaged loss experience at the three principal DOE sites: the Savannah River Site, Hanford Site, and Idaho National Environmental and Engineering Laboratory. The DOE sites were chosen because the operations and hazards would be representative of those encountered at commercial power reactor sites. Because lost workday cases are linked to the total recordable case experience (that is, each lost workday case would have to be included in the total recordable case category), the same DOE CAIRS data base period of record and facilities were used in the selection of the involved worker lost workday case incidence rate [200 lost workday cases in a workforce of 15,000 workers (0.013 lost workday case per full-time equivalent)].

The TRW (1994, all) study concluded that radiological impacts from handling incidents would be small. The total person-rem exposure for accidents in handling the four cask systems considered in the study would vary from 0.1 rem to 0.04 rem. This exposure would be the total for all persons who would be exposed, onsite workers as well as the public. The highest estimated exposure (0.1 person-rem) would result in 0.00005 latent cancer fatality in the exposed population.

The involved worker fatality incidence rate used was that also reported in the DOE CAIRS data base, but for the 1996 to 1997 (through the third quarter) period of record. The average DOE and contractor fatality rates used (2.9 fatalities among 100,000 workers) represent losses among workers operating equipment and handling waste materials at the principal DOE sites. This fatality incidence rate represents government and contractor experience in the DOE complex and operations that are governed by safety and administrative controls that would be similar to those used at commercial power reactor sites.

For comparison, the noninvolved worker total recordable case, lost workday case, and fatality incidence rates using the same data base sources are 0.033, 0.016, and 0.000029, respectively. However, because the CAIRS data base did not include fatality rates for noninvolved workers, the involved worker rate was used.

J.1.4.1.3 *Industrial Safety Impacts of DOE Loading Operations*

The technical approach and loss multipliers discussed in Section J.1.4.1.2 for commercial power reactor sites analysis were used for the analysis of spent nuclear fuel and high-level radioactive waste loading impacts at DOE sites. Because no information existed on the high-level radioactive waste loading duration for the truck and rail transportation modes, DOE assumed that the number of full-time equivalent involved workers for the two transportation modes would be the same as that for the DOE sites shipping spent nuclear fuel. For those sites, the average number of full-time equivalent workers would be about 0.07 and 0.12 per shipment for the truck and rail transportation modes, respectively.

J.1.4.2 Transportation Accident Scenarios

J.1.4.2.1 *Radiological Impacts of Transportation Accidents*

A potential consequence and risk of transportation would be accidents that released and dispersed radioactive material from safe containment in transportation packages. Such releases and dispersals, if they occurred, would lead to impacts to human health and the environment. The following sections describe the methods for analyzing the risks and consequences of accidents that could occur in the course of transporting spent nuclear fuel and high-level radioactive waste to a nuclear waste repository at the Yucca Mountain site. They discuss the bases for, and methods for, determining rates at which accidents are assumed to occur, the severity of these accidents, and the amounts of materials that could be released. Accident rates, severities, and the corresponding quantities of radioactive materials that could be released are essential data used in the analyses. Appendix A presents the quantities of radioactive materials in a typical pressurized-water reactor spent nuclear fuel assembly used in the analysis of accident consequences and risks. Legal-weight truck casks would contain as many as four pressurized-water reactor spent nuclear fuel assemblies, and rail casks would contain as many as 36 (see Table J-3).

In addition to accident rates and severities, an important variable in assessing impacts from transportation accident scenarios is the type of material that would be shipped. Accordingly, this appendix presents information used in the analyses of impacts of accidents that could occur in the course of transporting commercial pressurized- and boiling-water reactor fuels, DOE spent nuclear fuels, and DOE high-level radioactive waste.

POTENTIAL EFFECTS OF HUMAN ERROR ON ACCIDENT IMPACTS

The accident scenarios described in this chapter would be mostly a direct consequence of error on the part of transport vehicle operators, operators of other vehicles, or persons who maintain vehicles and rights-of-way. The number and severity of the accidents would be minimized through the use of trained and qualified personnel.

Others have argued that other kinds of human error could also contribute to accident consequences: (1) undetected error in the design and certification of transportation packaging (cask) used to ship radioactive material, (2) hidden or undetected defects in the manufacture of these packages, and (3) error in preparing the packages for shipment. DOE has concluded that regulations and regulatory practices of the Nuclear Regulatory Commission and the Department of Transportation address the design, manufacture, and use of transportation packaging and are effective in preventing these kinds of human error by requiring:

- Independent Nuclear Regulatory Commission review of designs to ensure compliance with requirements (10 CFR Part 71)
- Nuclear Regulatory Commission-approved and audited quality assurance programs for design, manufacturing, and use of transportation packages

In addition, Federal provisions (10 CFR Part 21) provide additional assurance of timely and effective actions to identify and initiate corrective actions for undetected design or manufacturing defects. Furthermore, conservatism in the approach to safety incorporated in the regulatory requirements and practices provides confidence that design or manufacturing defects that might remain undetected or operational deficiencies would not lead to a meaningful reduction in the performance of a package under normal or accident conditions of transportation.

For exposures to ionizing radiation following accidents, risks were analyzed in terms of dose and latent cancer fatalities to the public and workers. The analyses of risk also addressed the potential for fatalities that would be the direct result of mechanical forces and other nonradiological effects that occur in everyday vehicle and industrial accidents.

The transportation of spent nuclear fuel and high-level radioactive waste from the 77 sites to the Yucca Mountain site would be conducted in a manner that complied fully with regulations of the U.S. Department of Transportation and Nuclear Regulatory Commission. These regulations specify requirements that promote safety and security in transportation. The requirements apply to carrier operations; in-transit security; vehicles; shipment preparations; documentation; emergency response; quality assurance; and the design, certification, manufacture, inspection, use, and maintenance of packages (casks) that would contain the spent nuclear fuel and high-level radioactive waste.

Because of the high level of performance required by regulations for transportation casks (49 CFR Part 173 and 10 CFR Part 71), the Nuclear Regulatory Commission estimates that in 99.4 percent of rail and truck accidents no cask contents would be released (Fischer et al. 1987, page 9-10). The 0.6 percent of accidents that could cause a release of radioactive materials from casks can be described by a spectrum of accident severity. As the severity of an accident increases, the fraction of radioactive material contents that would be released from transportation casks also increases. However, as the severity of an accident increases it is less likely to occur. In its Modal Study (Fischer et al. 1987, all), the Nuclear Regulatory Commission developed an accident analysis methodology that uses this concept of a spectrum of severe accidents to calculate the probabilities and consequences of unlikely accidents that could occur in transporting highly radioactive materials.

Although the Nuclear Regulatory Commission approach, which was used in this EIS, provides a method for determining the frequency with which severe accidents can be expected to occur, their severity, and their consequences, a method does not exist for predicting where along routes accidents would occur. Therefore, for the analyses of impacts presented here the method used in the RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) is used. This method assumes that accidents could occur at any location along routes, with their frequency of occurrence being determined by the accident rate characteristic of the states through which the route passes and the number of shipments that travel the route.

The transportation accident scenario analysis evaluated radiological impacts to populations and to hypothetical maximally exposed individuals and estimated fatalities that could occur from traffic accidents. It included both rail and legal-weight truck transportation. The analysis used the RADTRAN4 (Neuhauser and Kanipe 1992, all) and RISKIND (Yuan et al. 1995, all) computer programs to determine accident consequences and risks. DOE has used both codes in recent DOE environmental impact statements (DOE 1995, Appendix J; DOE 1996a, Appendix E; DOE 1997b, Appendixes F and G) that address impacts of transporting radioactive materials. The analyses used seven kinds of information to determine the consequences and risks of accidents for populations:

- Routes from the 77 sites to the repository and their lengths in each state and population zone
- The number of shipments that would be transported over each route
- State-specific accident rates
- The kind and amount of radioactive material that would be transported in shipments
- Probabilities of release and fractions of cask contents that could be released in accidents

ESTIMATING ACCIDENT RISK

Assessing the radiological impact of accidents involves estimating the probability that an accident might occur and estimating the accident consequences. The probability, or chance, that an accident will occur is multiplied by the consequences of the accident to determine accident risk.

One method for estimating accident probabilities uses historic information on the rate at which accidents of a similar type or severity occur (accidents per vehicle-mile traveled). Information of this type is maintained as transportation accident data by the Department of Transportation and by transportation safety organizations in state governments. Accident rates are multiplied by the total number of miles that vehicles would travel to estimate the number of accidents.

Determining radiological accident consequences requires estimating the quantity of radionuclides likely to be released and the environmental transport mechanisms that would bring the radionuclides into contact with people and then calculating the resultant radiation dose. Because of the large amounts of data these calculations require, conservative or bounding assumptions are commonly used to simplify the calculation task. As a result, calculated risks tend to be overestimates.

- The number of people who could be exposed to accidents and how far they lived from the routes
- Exposure scenarios that include multiple exposure pathways, state-specific agricultural factors, and atmospheric dispersion factors for neutral and stable conditions applicable to the entire country for calculating radiological impacts

The analysis used the same routes and lengths of travel as the analysis of incident-free transportation impacts discussed above.

DOE used the CALVIN computer code discussed earlier, the DOE Throughput Study (TRW 1997, all), and information provided by the DOE National Spent Nuclear Fuel Program (Jensen 1998, all) to calculate the number of shipments from each site and, thus, the number of shipments that would use a particular route.

The state-specific accident rates (accidents and fatalities per kilometer of vehicle travel) used in the analysis included accident statistics for commercial motor carrier operations for the Interstate Highway System, other U.S. highways, and state highways for each of the 48 contiguous states (Saricks and Tompkins 1999, all). The analysis also used average accident and fatality rates for railroads in each state. The data specifically reflect accident and fatality rates that apply to commercial motor carriers and railroads.

Appendix A contains information on the radioactive material contents of shipments. Appendix A, Section A.2.1.5 describes the characteristics of the spent nuclear fuel and high-level radioactive waste that would be shipped. The analysis assumed that the average inventory of radioactive materials in shipments would be typical pressurized-water reactor spent nuclear fuel that had been removed from reactors for 25.8 years. Appendix A describes this inventory. The estimated impacts would be less if the analysis used the characteristics of a typical boiling-water reactor spent nuclear fuel, DOE spent nuclear fuel (including naval spent nuclear fuel, which the analysis assumed would be removed from reactors 5 years before its shipment to the repository), or high-level radioactive waste.

The analysis also used the number of people who potentially would be close enough to transportation routes at the time of an accident to be exposed to radiation or radioactive material released from casks, and the distances these people would be from the accidents. It used the HIGHWAY and INTERLINE computer programs to determine this estimated number of people and their distances from accidents. HIGHWAY and INTERLINE used 1990 Census data for this analysis. The analysis assumed that the region of influence extended 80 kilometers (50 miles) from an accident.

Accident Severity Categories and Conditional Probabilities

The classification scheme used in the Modal Study for both truck and rail transportation accidents is shown in Figure J-8. As shown, accident severity is a function of two variables. The first variable is the mechanical force that occurs in impacts. In the figure, mechanical force is represented by the deformation (strain) in a cask's containment (inner shell) that the force would cause. The second variable is thermal energy, or the heat input to a cask engulfed by fire. In the figure, thermal energy is represented by the midpoint temperature of a cask's lead shield wall following heating, as in a fire.

Because all accident scenarios that would involve casks can be described in these terms, the severity of accidents can be analyzed independently of specific accident sequences. In other words, any sequence of events that results in an accident in which a cask is subjected to mechanical forces, within a certain range of values, and possibly fire is assigned to the accident severity category associated with the applicable ranges for the two parameters. This accident severity scheme enables analysis of a manageable number of accident situations while accounting for all reasonably foreseeable transportation accidents, including accidents with low probabilities but high consequences and those with high probabilities but low consequences.

For the analysis of impacts, a conditional probability was assigned to each accident severity category. Figure J-8 also shows the conditional probabilities developed in the Modal Study for the accident severity matrix. These conditional probabilities are used in the analysis of impacts presented in this chapter. The conditional probabilities are the chances that accidents will involve the mechanical forces and the heat energy in the ranges that apply to the categories. For example, accidents that would fall into the category labeled R(1,1), which represents the least severe accident in the matrix, would be likely to make up 99.4 percent of all accidents that would involve truck and railcar shipments of casks carrying spent nuclear fuel or high-level radioactive waste. The mechanical forces and heat in accidents in this category would not exceed the regulatory design standards for casks. Using the information in the figure, an accident in this category could cause a maximum of 0.2 percent strain (deformation) in a cask's containment and could heat the lead shielding to 260ºC (500ºF) degrees. These damage conditions are within the range of damage that would occur to casks subjected to the hypothetical accident conditions tests that Nuclear Regulatory Commission regulations require a cask to survive (10 CFR Part 71). Category R(4,5)-accidents, which would cause extensive damage to a cask, are very severe but very infrequent. The Category R(4,5) accidents would occur an estimated 3.4 times in each 100 trillion rail accidents and less than one time in each 10 quadrillion truck accidents.

The analysis of accident risks presented in this appendix used the frequency that would be likely for accidents in each of the severity categories. This frequency was determined by multiplying the category's conditional probability by the accident rates for each state's urban, suburban, and rural population zones and by the shipment distances in each of these zones, and then adding the results. The accident rates in the population density zones in each state are distinct and correspond to traffic conditions, including average vehicle speed, traffic density, and other factors, including rural, suburban, or urban location.

In terms of potential to release radioactivity to the environment, the most severe of reasonably foreseeable accidents are those that would fall into one of the eight categories of very severe accidents. For these eight categories, the fractions and characteristics of radioactive materials that would be released in an

Structural response (maximum strain on inner shell, percent)

S_3 (30)

S_2 (2)

S_1 (0.2)

P_t P_r	R(4,1) 1.532×10^{-7} 1.786×10^{-9}	R(4,2) 3.926×10^{-14} 3.290×10^{-13}	R(4,3) 1.495×10^{-14} 2.137×10^{-13}	R(4,4) 7.681×10^{-16} 1.644×10^{-13}	R(4,5) $<1 \times 10^{-16}$ 3.459×10^{-14}
P_t P_r	R(3,1) 1.7984×10^{-3} 5.545×10^{-4}	R(3,2) 1.574×10^{-7} 1.021×10^{-7}	R(3,3) 2.034×10^{-7} 6.634×10^{-8}	R(3,4) 1.076×10^{-7} 5.162×10^{-8}	R(3,5) 4.873×10^{-8} 5.296×10^{-8}
P_t P_r	R(2,1) 3.8192×10^{-3} 2.7204×10^{-3}	R(2,2) 2.330×10^{-7} 5.011×10^{-7}	R(2,3) 3.008×10^{-7} 3.255×10^{-7}	R(2,4) 1.592×10^{-7} 2.531×10^{-7}	R(2,5) 7.201×10^{-8} 1.075×10^{-8}
P_t P_r	R(1,1) 0.994316 0.993962	R(1,2) 1.687×10^{-5} 1.2275×10^{-3}	R(1,3) 2.362×10^{-5} 7.9511×10^{-4}	R(1,4) 1.525×10^{-5} 6.140×10^{-4}	R(1,5) 9.570×10^{-6} 1.249×10^{-4}

T_1 (500) T_2 (600) T_3 (650) T_4 (1,050)

Thermal response (lead mid-thickness temperature, °F)

Legend

R(x,y) = The label used to identify the cell in the accident response matrix located at the x row from the bottom of the matrix and y column from the left of the matrix. Thus, (R1,1) is the identifier for the cell in the lower left corner of the matrix.

P_t = Probability of occurrence assuming a truck accident occurs.

P_r = Probability of occurrence assuming a rail accident occurs.

Note:
- Maximum strain between 0 and 0.2 percent (S_1) for the inner shell of a cask would be within the design conditions for a Nuclear Regulatory Commission-certified shipping cask. There would be permanent deformation after the load is removed. S_1 strains could occur in impacts against medium hardness structures (for example, bridge abutments) at speeds up to 100 kilometers (60 miles per hour).
- Strains between 0.2 and 2 percent (S_2) would result in small permanent deformations. S_2 strains could occur in impacts against medium hardness structures at speeds up to 130 kilometers (80 miles per hour).
- Strains between 2 and 30 percent (S_3) would result in large permanent deformations. S_3 strains could occur in impacts against medium hardness structures at speeds greater than 130 kilometers (80 miles per hour).

Source: Fischer et al. (1987, pages 4-8, 7-25, and 7-26).

Figure J-8. Probability matrix for mechanical forces and heat in transportation accidents.

accident were estimated to be the same. That is, for a shipment of spent nuclear fuel that is involved in an accident classified as Category R(4,1), the amount and characteristics of radioactive material assumed to be released would be the same as those for an accident that would fall into Category R(4,2), R(4,3), R(4,4), R(4,5), R(1,5), R(2,5), or R(3,5). Because the releases of radioactive materials that could occur are assumed to be the same for each of these eight categories, the probabilities of occurrence can be summed. This sum is used to calculate a collective probability for the most severe of the accidents addressed in this analysis. Thus, the conditional probability of a truck accident of the greatest severity that is analyzed would be 0.0000098 per accident event (about 1 chance in 100,000 per accident).

By combining categories for which the releases of radioactive materials are assumed to be equivalent, the 20 accident categories in Figure J-8 are reduced to six collective categories. The first is the same as severity category R(1,1); the second collects severity categories R(1,2) and R(1,3); the third R(2,1), R(2,2) and R(2,3); the fourth R(3,1), R(3,2) and R(3,3); the fifth, R(1,4), R(2,4), and R(3,4); and, as discussed above, the sixth collects R(4,1) through R(4,5) and R(1,5) through R(3,5).

Accident Releases

Radiological consequences were calculated by assigning cask release fractions to each accident severity category for each chemically and physically distinct radioisotope. The *release fraction* is defined as the fraction of the radioactivity in the cask that could be released from the cask in a given severity of accident. Release fractions vary according to spent nuclear fuel type and the physical/chemical properties of the radioisotopes. Most radionuclides in spent nuclear fuel are in chemically and physically stable, solid, nondispersible forms. Gaseous radionuclides, such as krypton-85, would be released if both the fuel cladding and cask containment boundary were compromised.

The Modal Study developed release fractions for commercial spent nuclear fuel from pressurized-water reactors. These release fractions, listed in Table J-21, are based on best engineering judgment and are believed to be conservative. 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 (see Table J-3) and the radionuclide activity of a spent nuclear fuel assembly (see Appendix A). To provide perspective, the release fraction for a category 6 accident involving a large rail cask results in an estimated release of about 1,600 curies of cesium isotopes. For this analysis, the release fractions developed by the Modal Study were used only for commercial pressurized-water reactor fuel and spent nuclear fuel from training, research and isotope reactors built by General Atomics (commonly called *TRIGA* spent nuclear fuel), both of which are rod-type fuels. The availability of fuel-specific data for other types of spent nuclear fuel that would be shipped to the repository allowed the use of release fractions that more closely approximate expected release characteristics.

Table J-21. Fractions of selected radionuclides in commercial spent nuclear fuel projected to be released from casks in transportation accidents for cask response regions.

		Release fraction[a]				
Cask response region	Severity category	Inert gas	Iodine-129	Cesium-134, -135, -137	Ruthenium-106	Particulates
R(1,1)	1	0.0	0.0	0.0	0.0	0.0
R(1,2),R(1,3)	2	9.9×10^{-3}	7.5×10^{-5}	6.0×10^{-6}	8.1×10^{-7}	6.0×10^{-8}
R(2,1),R(2,2),R(2,3)	3	3.3×10^{-2}	2.5×10^{-4}	2.0×10^{-5}	2.7×10^{-6}	2.0×10^{-7}
R(3,1),R(3,2),R(3,3)	4	3.3×10^{-1}	2.5×10^{-3}	2.0×10^{-4}	2.7×10^{-5}	2.0×10^{-6}
R(1,4),R(2,4),R(3,4)	5	3.9×10^{-1}	4.3×10^{-3}	2.0×10^{-4}	4.8×10^{-5}	2.0×10^{-6}
R(1,5),R(2,5),R(3,5),R(4,5), R(4,1),R(4,2),R(4,3),R(4,4)	6	6.3×10^{-1}	4.3×10^{-2}	2.0×10^{-3}	4.8×10^{-4}	2.0×10^{-5}

a. Source: (DOE 1995, page I-86).

Release fractions for aluminum fuels (aluminum alloy fuel, aluminum cladding) were based on laboratory measurements and the U.S. Nuclear Regulatory Commission Modal Study (Fischer et al. 1987, all). Because of the lower melting point of aluminum compared to metals used in other metallic fuels, the aluminum fuel release fractions are considered bounding for metallic fuels (that is, Savannah River Production Reactor, Hanford N-Reactor, and Experimental Breeder Reactor-II Mark V spent nuclear fuel). Release fractions for the aluminum and other metallic fuel types are listed in Table J-22. The estimates of fractions for cask contents released in severe accidents were assumed to be independent of the type of cask.

Table J-22. Fractions of selected radionuclides in aluminum and metallic spent nuclear fuel projected to be released from casks in transportation accidents for cask response regions.[a]

		Release fraction[b]				
Cask response region	Severity category	Inert gas	Iodine-129	Cesium-134, -135, -137	Ruthenium-106	Particulates
R(1,1)	1	0.0	0.0	0.0	0.0	0.0
R(1,2),R(1,3)	2	9.9×10^{-3}	1.1×10^{-7}	3.0×10^{-8}	4.1×10^{-9}	3.0×10^{-10}
R(2,1),R(2,2),R(2,3)	3	3.3×10^{-2}	3.5×10^{-7}	1.0×10^{-7}	1.4×10^{-8}	1.0×10^{-9}
R(3,1),R(3,2),R(3,3)	4	3.3×10^{-1}	3.5×10^{-6}	1.0×10^{-6}	1.4×10^{-7}	1.0×10^{-8}
R(1,4),R(2,4),R(3,4)	5	3.9×10^{-1}	6.0×10^{-6}	1.0×10^{-6}	2.4×10^{-7}	1.0×10^{-8}
R(1,5),R(2,5),R(3,5),R(4,5), R(4,1),R(4,2), R(4,3),R(4,4)	6	6.3×10^{-1}	6.0×10^{-5}	1.0×10^{-5}	2.4×10^{-6}	1.0×10^{-7}

a. Source: DOE (1995, page I-87).

b. These release fractions are applicable to N-Reactor, Savannah River Site production reactor, and DOE research/test reactor spent nuclear fuel types.

Atmospheric Conditions

For the analyses of accident risk and consequences, releases of radioactive materials from casks during and following severe accidents were assumed to be into the atmosphere where these materials would be carried by wind. Because it is not possible to predict specific locations where transportation accidents would occur, atmospheric conditions that generally apply throughout the continental United States were used.

Table J-23 lists the frequency at which atmospheric stability and wind speed conditions occur in the contiguous United States. The data, which are averages for 177 meteorological data collection locations, were used in conjunction with the RISKIND computer program (Yuan et al. 1995, all) to develop estimates of the consequences of maximum reasonably foreseeable accidents and acts of sabotage.

In calculating estimated values for consequences, RISKIND used the atmospheric stability and wind speed data to analyze the dispersion of radioactive materials in the atmosphere that could follow releases in severe accidents. The dispersions were modeled as plumes of gases and particles. Using the results of the dispersion analysis, RISKIND calculated values for radiological consequences (population dose and dose to a maximally exposed individual). These results were placed in order from lowest to highest. Following this order, the probabilities of the atmospheric conditions associated with each set of consequences were accumulated. As the accumulated probability increased and the likelihood of an exceedance of a set of atmospheric conditions decreased, estimated consequences increased. This procedure was followed to identify the level of severe accident and sabotage consequences that would not be exceeded 50 percent and 95 percent of the time. For atmospheric conditions that are called neutral, or average, the consequences would not be exceeded 50 percent of the time. Thus, neutral atmospheric conditions would be the conditions likely to prevail during a severe accident or act of sabotage. Under stable, or quiescent, conditions the consequences would not be exceeded 95 percent of the time. The

Table J-23. Frequency of atmospheric and wind speed conditions – U.S. averages.[a]

Atmospheric stability class	Wind speed condition						Total
	WS(1)	WS(2)	WS(3)	WS(4)	WS(5)	WS(6)	
A	0.00667	0.00444	0.00000	0.00000	0.00000	0.00000	0.01111
B	0.02655	0.02550	0.01559	0.00000	0.00000	0.00000	0.06764
C	0.01400	0.02931	0.05724	0.01146	0.00122	0.00028	0.11351
D	0.03329	0.07231	0.15108	0.16790	0.03686	0.01086	0.47230
E	0.00040	0.04989	0.06899	0.00146	0.00016	0.00003	0.12093
F	0.10771	0.08710	0.00110	0.00000	0.00000	0.00000	0.19591
G	0.01713	0.00146	0.00000	0.00000	0.00000	0.00000	0.01859
F+G	0.12485	0.08856	0.00110	0.00000	0.00000	0.00000	0.21451
Totals	**0.20576**	**0.27000**	**0.29401**	**0.18082**	**0.03825**	**0.01117**	**1.00000**
Wind speed (meters per second)[b]	0.89	2.46	4.47	6.93	9.61	12.52	

a. Source: TRW (1999a, page 40).
b. To convert meters per second to miles per hour, multiply by 2.237.

analysis assumed that these conditions, which would be unlikely, would occur only for maximum reasonably foreseeable accidents that had an annual probability greater than 2 chances in 1 million in a year.

Exposure Pathways

Radiation doses were calculated for an individual who is postulated to be near the scene of an accident and for populations within 80 kilometers (50 miles) of an accident location. Doses were determined for rural, suburban, and urban population groups. Dose calculations considered a variety of exposure pathways, including inhalation and direct exposure (cloudshine and immersion in a plume of radioactive material) from a passing cloud of contaminants; ingestion from contaminated crops; direct exposure from radioactivity deposited on the ground (groundshine); and inhalation of radioactive particles resuspended by wind from the ground.

Emergency Response, Interdiction, Dose Mitigation, and Evacuation

The RADTRAN4 computer program that DOE used to estimate radiological risks includes assumptions about the postaccident remediation of radioactive material contamination of land where people live. The program assumed that, after an accident, contaminants would continue to contribute to population dose through three pathways—groundshine, inhalation of resuspended particulates, and, for accidents in rural areas, ingestion of foods produced on the contaminated lands. It also assumed that medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of accidents.

Similarly, the RISKIND (Yuan et al. 1995, all) computer program includes assumptions about response, interdiction, dose mitigation, and evacuation for calculating radiological consequences (dose to populations and maximally exposed individuals). In estimating consequences of maximum reasonably foreseeable accidents during the transportation of spent nuclear fuel and high-level radioactive waste to the repository, the analysis assumed the following:

- Populations would continue to live on contaminated land for 1 year.

- There would be no radiological dose to populations from ingestion of contaminated food. Food produced on land contaminated by a maximum reasonably foreseeable accident would be embargoed from consumption.

- Medical and other interdiction would not occur to reduce concentrations of radionuclides absorbed or deposited in human tissues as a result of an accident.

The analysis of radiological risks to populations and estimates of consequences of maximum reasonably foreseeable accidents did not explicitly address local, difficult-to-evacuate populations such as those in prisons, hospitals, nursing homes, or schools. However, the analysis addressed the potential for accidents to occur in urban areas with high population densities and used the assumptions regarding interdiction, evacuation, and other intervention actions discussed above. These assumptions encompass the consequences and risks that could arise from slowness in preventing the consequences of an accident for some population groups.

Health Risk Conversion Factors

The health risk conversion factors used to estimate expected latent cancer fatalities from radiological exposures are presented in International Commission on Radiological Protection Publication 60 (ICRP 1991, page 22). These factors are 0.0005 latent cancer fatality per person-rem for members of the public and 0.0004 latent cancer fatality per person-rem for workers. For accidents in which individuals would receive doses greater than 20 rem over a short period (high dose/high dose rate), the factors would be 0.0010 latent cancer fatality per rem for a member of the public and 0.0008 latent cancer fatality per rem for workers.

Assessment of Accident Risk

The RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) was used in calculating risks from transportation of spent nuclear fuel and high-level radioactive waste. The code determined unit-risk factors (person-rem per curie) for the radionuclides of concern in the inventory being shipped. The unit-risk factors from RADTRAN4 were combined with conditional accident probabilities, state-specific accident rates, release fractions for each of the six accident severity collective categories, and state-specific food transfer factors to obtain risk per shipment for routes. The accident risks were estimated in terms of collective radiation dose to the population within 80 kilometers (50 miles).

The analysis first calculated unit risk factors for a shipment for each state through which shipments would pass. This was done for the three types of population zones in each state (using population density data from the 1990 census) and for each accident severity category. The unit risk factors used actual population densities within 800 meters (0.5 mile) of routes based on 1990 census data to estimate populations within 80 kilometers (50 miles). This yielded values for each transportation mode, for each type of impact, and for each state through which a shipment would pass. The unit risk factors for all the applicable accident severity categories were summed for each population zone for each state. Also, for the three types of population zone in a state, the lengths through areas of each type were summed for the route used in the analysis. This yielded route lengths for each population zone in each state. The sum of the route lengths and the sum of the unit risk factors for each population zone were multiplied together. This was repeated for each population zone in each state through which a shipment would pass. The results were summed to provide estimates of the accident risk for a shipment.

Estimating Consequences of Maximum Reasonably Foreseeable Accident Scenarios

In addition to analyzing the radiological and nonradiological risks that would result from the transportation of spent nuclear fuel and high-level radioactive waste to the repository, DOE assessed the consequences of maximum reasonably foreseeable accidents. This analysis provided information about the magnitude of impacts that could result from the most severe accident that could reasonably be expected to occur, although it could be highly unlikely. DOE concluded that, as a practical matter, events with a probability less than 1×10^{-7} (1 chance in 10 million) per year rarely need to be examined (DOE 1993, page 28). This would be equivalent to about once in the course of 15 billion legal-weight truck shipments. For perspective, an accident this severe in commercial truck transportation would occur about once in 50 years on U.S. highways. Thus, the analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of spent nuclear fuel and high-level radioactive waste evaluated only consequences for accidents with a probability greater than 1×10^{-7} per year. The consequences were determined for atmospheric conditions that could prevail during accidents and for physical and biological pathways that would lead to exposure of members of the public and workers to radioactive materials and ionizing radiation. The analysis used the RISKIND code (Yuan et al. 1995, all) to estimate doses for individuals and populations.

The analysis assumed maximum reasonably foreseeable accident scenarios could occur anywhere, either in rural or urbanized areas. The probability of such an accident would depend on the amount of exposure to the transportation accident environment. In this case, exposure would be the product of the cumulative shipment distance and the applicable accident rates. However, because of large differences in exposure, principally because of the large differences in the distances traveled in the two types of population areas, a severe accident scenario that might be reasonably foreseeable, in a rural area might not be reasonably foreseeable in an urbanized area. Thus, a reasonably foreseeable accident postulated to occur in a rural area (most travel would occur in rural areas) under meteorological conditions that would be exceeded (resulting in greater consequences) only 5 percent of the time, might not be reasonably foreseeable in an urbanized area where shipments would travel relatively few kilometers. For the mostly legal-weight truck and mostly rail scenarios, Table J-24 lists the probability of a severe accident during national transportation. These probabilities are for accidents that would:

- Occur in urbanized and rural areas
- Occur under median (50-percent) meteorological conditions and 95-percent conditions (95-percent conditions would be exceeded, in terms of dose consequences, only 5 percent of the time)
- Occur for accidents in collective severity categories 5 and 6 that are postulated to result in the largest releases of radioactive materials from shipping casks
- Involve rail and legal-weight truck casks

Table J-24. Annual probability of severe accidents in urbanized and rural areas – category 5 and 6 accidents, national transportation.

		Probability of exceeding threshold for Category 5		Probability of exceeding threshold for Category 6	
Scenario	Meteorologic conditions exceeded	Annual probability for urbanized area	Annual probability for rural area	Annual probability for urbanized area	Annual probability for rural area
Mostly rail					
Truck shipments	50%	4×10^{-7}[a]	2×10^{-6}	3×10^{-7}	1×10^{-6}
	95%	$\mathbf{2\times10^{-8}}$**[b]**	1×10^{-7}	$\mathbf{1\times10^{-8}}$	$\mathbf{7\times10^{-8}}$
Rail shipments	50%	1×10^{-5}	4×10^{-5}	3×10^{-6}	8×10^{-6}
	95%	7×10^{-7}	2×10^{-6}	2×10^{-7}	4×10^{-7}
Mostly legal-weight truck					
Truck shipments	50%	6×10^{-6}	4×10^{-5}	4×10^{-6}	2×10^{-5}
	95%	3×10^{-7}	2×10^{-6}	2×10^{-7}	1×10^{-6}
Rail shipments	50%	$\mathbf{4\times10^{-8}}$	1×10^{-6}	$\mathbf{8\times10^{-9}}$	4×10^{-7}
	95%	$\mathbf{2\times10^{-9}}$	$\mathbf{5\times10^{-8}}$	$\mathbf{4\times10^{-10}}$	$\mathbf{2\times10^{-8}}$

a. Probabilities not in bold are reasonably foreseeable.
b. Probabilities in bold would occur less than one time in 10 million and therefore are not reasonably foreseeable.

For the mostly legal-weight truck scenario, in which only naval spent nuclear fuel would be shipped by rail, the likelihood would be less than 1×10^{-7} per year for the most severe rail accident (severity category 6) to occur in an urbanized area. Thus, the highest severity rail accidents would only be reasonably foreseeable in rural areas under average (50-percent) meteorological conditions (probability greater than 1 in 10 million per year).

Table J-24 also lists the probabilities of other severe accidents the analysis considered. Under the mostly rail scenario, the most severe types of legal-weight truck accidents (collective category 6) in rural and urbanized areas under meteorological conditions that would be exceeded only 5 percent of the time would not be reasonably foreseeable.

In total, 9 sets of accident conditions defined by scenario, shipment mode, meteorology, accident severity category, and location (identified in the table by shaded cells) would not be reasonably foreseeable. Nonetheless, although the probabilities would be remote for some accidents, the RADTRAN4 analysis of radiological dose-risks (discussed above) included risk contributions of all accidents, including ones in categories 1 through 4, regardless of their probability of occurrence or consequences. Thus, the analysis addressed the contributions to risk from the spectrum of accidents that would range from low-consequence, high-probability events to high-consequence, low-probability events.

The analysis of maximum reasonably foreseeable accidents evaluated only accidents from the 23 listed in Table J-24 that would be reasonably foreseeable and that could result in maximum consequences.

From this collection of 23 possible accidents, the analysis evaluated three sets of accident conditions that were determined as those with the greatest consequences—one for the mostly rail scenario and two for the mostly legal-weight truck scenario—to identify the maximum reasonably foreseeable accident that would have the greatest consequences. The results for these cases are listed in Table J-25. Based on these results, the analysis identified one maximum reasonably foreseeable accident each for the mostly rail and mostly legal-weight truck national transportation analysis scenarios. For the mostly legal-weight truck scenario, the maximum reasonably foreseeable accident would be a severity category 6 accident involving a legal-weight truck cask in an urbanized area under stable weather (meteorological conditions that would be exceeded only about 5 percent of the time) conditions. For the mostly rail scenario, the accident would also be a category 6 accident involving a rail cask in an urbanized area under stable weather conditions.

The analysis of consequences of maximum reasonably foreseeable accidents used data from the 1990 census to estimate the size of populations in urbanized areas that could receive exposures to radioactive materials. The analysis used estimated populations in successive 8-kilometer (5-mile)-wide annular rings around the centers of the 21 large urbanized areas (cities and metropolitan areas) in the continental United States (TRW 1999a, page 22). The average population for each ring was used to form a population distribution for use in the analysis. To be conservative in estimating consequences, the analysis assumed that accidents in urbanized areas would occur at the center of the population zone, where the population density would be greatest. This assumption resulted in conservative estimates of collective dose to exposed populations.

J.1.4.2.2 *Methods and Approach for Analysis of Nonradiological Impacts of Transportation Accidents*

Nonradiological accident risks are risks of traffic fatalities. Traffic fatality rates are reported by state and Federal transportation departments as fatalities per highway vehicle- or train-kilometer traveled. The fatalities are caused by physical trauma in accidents. For nonradiological accident risks estimated in this EIS for legal-weight truck transportation, accident fatality risks were based on state-level fatality rates for Interstate Highways (Saricks and Tompkins 1999, all). Accident fatality risks for rail transportation were

Table J-25. Consequences of maximum reasonably foreseeable accidents in national transportation.

Scenario	Meteorologic conditions exceeded	Severity category 5 accidents: Consequences in urbanized area	Severity category 5 accidents: Consequences in rural area	Severity category 6 accidents: Consequences in urbanized area	Severity category 6 accidents: Consequences in rural area
Mostly rail					
Truck accident	50%	+[a]	+	+	+
	95%	--[b]	+	--	--
Rail accident	50% population dose	+	+	+	+
	50% MEI[c] dose	+	+	+	+
	95% population dose	+	+	61,000 (31)[d]	+
	95% MEI dose	+	+	26 (0.013)[e]	+
Mostly legal-weight truck					
Truck accident	50% population dose	++[f]	++	++	++
	50% MEI dose	++	++	++	++
	95% population dose	++	++	9,400 (5)	430 (0.2)
	95% MEI dose	++	++	4 (0.002)	3.9 (0.002)
Rail accident	50%	--	++	--	++
	95%	--	--	--	--

a. + = Consequences of these accidents are bounded by the rail accident in an urbanized area.
b. = probability less than 1 × 10-7 (not reasonably foreseeable).
c. MEI = maximally exposed individual.
d. Population consequence in person-rem (latent cancer fatality).
e. MEI consequences in rem (probability of increasing a latent cancer fatality).
f. ++ = Consequences of these accidents are bounded by the truck accident in an urbanized area.

also calculated using state-specific rates (Saricks and Tompkins 1999, all). Section J.2.1 discusses methods and data used to analyze accidents for barge transportation.

For truck transportation, the rates in Saricks and Tompkins (1999, Table 4) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are multiaxle tractor-trailer trucks having a tractor and one to three freight trailers connected to each other. This kind of truck with a single trailer would be used to ship spent nuclear fuel and high-level radioactive waste. Truck accident rates were determined for each state based on statistics compiled by the Department of Transportation Office of Motor Carriers for 1994 through 1996. The report presents accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement, fatality, and injury rates for the 3 years investigated. Fatalities include crew members and all others attributed to accidents. Although escort vehicles would not be heavy combination trucks, the fatality rate data used for truck shipments of loaded and empty spent fuel casks were also used to estimate fatalities from accidents that would involve escort vehicles.

Rail accident rates were computed and presented similarly to truck accident rates, but a railcar is the unit of haulage. The state-specific rail accident involvement and fatality rates are based on statistics compiled by the Federal Railroad Administration for 1994 through 1996. Rail accident rates include both mainline accidents and those occurring in railyards (Saricks and Tompkins 1999, page 9).

The accident rates used to estimate traffic fatalities were computed using data for all interstate shipments, independent of the cargoes. Shippers and carriers of radioactive material generally have a higher-than-average awareness of transport risk and prepare cargoes and drivers accordingly (Saricks and Kvitek 1994, all). These effects were not given credit in the assessment.

J.1.4.2.3 *Data Used To Estimate Incident Rates for Rail and Motor Carrier Accidents*

In analyzing potential impacts of transporting spent nuclear fuel and high-level radioactive waste, DOE considered both incident-free transportation and transportation accidents. Potential incident-free transportation impacts would include those caused by exposing the public and workers to low levels of radiation and other hazards associated with the normal movement of spent nuclear fuel and high-level radioactive waste by truck, rail, or barge. Impacts from accidents would be those that could result from exposing the public and workers to radiation, as well as vehicle-related fatalities.

In its analysis of impacts from transportation accidents, DOE relied on data collected by the U.S. Department of Transportation and others (for example, the American Petroleum Institute) to develop estimates of accident likelihood and their ranges of severity (see Fischer et al. 1987, pages 7-25 and 7-26). Using these data, the analysis estimated that as many as 40 accidents could occur over 24 years in the course of shipping spent nuclear fuel to the repository by legal-weight trucks; 1 or 2 rail accidents that involved a railcar carrying a cask could occur if most shipments were by rail; and no accidents would be likely for the limited use of barges.

Furthermore, in using data collected by the Department of Transportation, the analysis considered the range of accidents, from slightly more than “fender benders” to high-speed crashes, that the DOE carrier would have to report in accordance with the requirements of Department of Transportation regulations. The accidents that could occur would be unlikely to be severe enough to affect the integrity of the shipping casks.

The following paragraphs discuss reporting and definitions for transportation accidents and the relationships of these to data used in analyzing transportation impacts in this EIS.

J.1.4.2.3.1 Transportation Accident Reporting and Definitions. In the United States, the reporting of transportation accidents and incidents involving trucks, railroads, and barges follows requirements specified in various Federal and state regulations.

Motor Carrier Accident Reporting and Definitions

Regulations generally require the reporting of motor carrier accidents (regardless of the cargo being carried) if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a functional threshold for damage to vehicles rather than a value-of-damage threshold, which was used until the 1980s. Nonetheless, many states continue to use value thresholds (for example, Ohio uses $500) for vehicle damage when documenting reportable accidents.

Until March 4, 1993, Federal regulations (49 CFR Part 394) required motor carriers to submit accident reports to the Federal Highway Administration Motor Carrier Management Information System using the so-called “50-T” reporting format. The master file compiled from the data on these reports in the Federal Highway Administration Office of Motor Carriers was the basis of accident, fatality, and injury rates developed for the 1994 study of transportation accident rates (Saricks and Kvitek 1994, all).

The Final Rule of February 2, 1993 (58 *FR* 6726, February 2, 1993), modified the carrier reporting requirement; rather than submitting reports, carriers now must maintain a register of accidents that meet the definition of an accident for 1 year after such an accident occurs. Carriers must make the contents of such a register available to Federal Highway Administration agents investigating specific accidents. They must also give “…all reasonable assistance in the investigation of any accident including providing a full, true, and correct answer to any question of inquiry” to determine if hazardous materials other than spilled

COMMERCIAL MOTOR VEHICLE ACCIDENT
(49 CFR 390.5)

An occurrence involving a commercial motor vehicle operating on a public road in interstate or intrastate commerce that results in:

- A fatality
- Bodily injury to a person who, as a result of the injury, immediately receives medical treatment away from the scene of the accident
- One or more motor vehicles incurring disabling damage as a result of the accident, requiring the motor vehicle to be transported away from the scene by a tow truck or other motor vehicle

The term accident does not include:

- An occurrence involving only boarding and alighting from a stationary motor vehicle
- An occurrence involving only the loading or unloading of cargo
- An occurrence in the course of the operation of a passenger car or a multipurpose passenger vehicle by a motor carrier and is not transporting passengers for hire or hazardous materials of a type and quantity that require the motor vehicle to be marked or placarded in accordance with 49 CFR Part 177, Subpart 823

fuel from the fuel tanks were released, and to furnish copies of all state-required accident reports [49 CFR 390.15]. The reason for this rule change was the emergence of an automated State accident reporting system compiled from law enforcement accident reports that, pursuant to provisions of the Intermodal Surface Transportation Efficiency Act of 1991 [P.L. 102-240, 105 STAT. 1914], was established under the Motor Carrier Safety Assistance Program.

Under Section 408 of Title IV of the Motor Carrier Act of 1991, a component of the Intermodal Surface Transportation Efficiency Act, the Secretary of Transportation is authorized to make grants to states to help them achieve uniform implementation of the police reporting system for truck and bus accidents recommended by the National Governors Association. Under this system, called SAFETYNET, accident data records generated by each state follow identical formatting and content instructions. They are entered in a Federally maintained SAFETYNET data base on approximately a weekly basis. The SAFETYNET data base, in turn, is compiled and managed as part of the Motor Carrier Management Information System.

Accident data compiled from the Bureau of Motor Carrier Safety (now the Office of Motor Carriers in the Federal Highway Administration), American Petroleum Institute, California Highway Patrol, and California Department of Transportation provided the basis used by the Modal Study (Fischer et al. 1987, page B-1) for estimating characteristics of accidents that might involve shipments of spent nuclear fuel using "large trucks." Although reporting requirements have changed, these data were similar to data being compiled by the SAFETYNET system for motor carrier accidents in 1999. Most important, the definition of a motor carrier accident, the basis for reporting and data compilation, has remained basically unchanged over the 40 years of data collection.

Because the Modal Study is the fundamental source for data that describes the severity of transportation accidents used in this EIS, the relative constancy of the definition of *accident* is important in establishing confidence in estimated impact results. Thus, although the transportation environment has changed over the 40 years of data collection, the constancy of the definition of *accident* tends to provide confidence that the distribution of severity for reported accidents has remained relatively the same. That is, low-consequence, fender-bender accidents are the most common, high-consequence, highly energetic accidents are rare, and the proportions of these have remained roughly the same.

Changes in the transportation environment, such as changes in speed limits and safety technology, tend to change the accident rate (accidents per vehicle-kilometer of travel). Overall, however, given that the definition of *accident* does not change, such changes do not greatly affect the distribution of accident severities. For example, recent increases in speed limits from 105 to 121 kilometers (65 to 75 miles) per hour represent about a 25-percent increase in the maximum mechanical energy of vehicles. Other information aside, this increase could lead to the conclusion that the resulting distribution of accidents would show an increase for the most severe accidents in comparison to minor accidents. However, the speed limit increases do not represent a corresponding increase in actual traffic speeds, and would be unlikely to change the distribution of velocities and, thus, mechanical energies, of severe accidents from those reported in the Modal Study. These velocities ranged to faster than 137 kilometers (85 miles) per hour, even though at the time the National speed limit was 89 kilometers (55 miles) per hour.

Rail Carrier Accident Reporting and Definitions

As with regulations governing the reporting of motor carrier accidents, Federal Railroad Administration regulations generally require the reporting of accidents if there are injuries, fatalities, or property damage. These regulations have evolved through the years, mostly in response to increasing values of transportation equipment and commodities. For example, the Federal requirements in the following text box establish a value-based reporting threshold for damage to vehicles; the value has been indexed to inflation since 1975.

RAILROAD ACCIDENT/INCIDENT
(49 CFR 225.11)

- An impact between railroad on-track equipment and an automobile, bus, truck, motorcycle, bicycle, farm vehicle or pedestrian at a highway-rail grade crossing
- A collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in reportable damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed
- An event arising from the operation of a railroad which results in:
  - Death to any person
  - Injury to any person that requires medical treatment
  - Injury to a railroad employee that results in:
- A day away from work
- Restricted work activity or job transfer
- Loss of consciousness
- Occupational illness

Rail carriers covered by these requirements must fulfill several bookkeeping tasks. The Federal Railroad Administration requires the submittal of a monthly status report, even if there were no reportable events during the period. This report must include accidents and incidents, and certain types of incidents require immediate telephone notification. Logs of reportable injuries and on-track incidents must be maintained by the railroads on which they occur, and a listing of such events must be posted and made available to employees and to the Federal Railroad Administration, along with required records and reports, on request. The data entries extracted from the reporting format are consolidated into an accident/incident data base that separates reportable *accidents* from grade-crossing *incidents*. These are processed annually into event, fatality, and injury count tables in the Federal Railroad Administration's *Accident/Incident*

Bulletin (Saricks and Tompkins 1999, all), which the Office of Safety publishes on the Internet (*http://safetydata.fra.dot.gov/officeofsafety/Prelim/1999/r01.htm*).

In contrast to the regulations for motor carriers discussed above, the Federal Railroad Administration regulations cited above call for the reporting of accidents and incidents. According to the Modal Study, the Administration defines an *accident* as "any event involving on-track railroad equipment that results in damage to the railroad on-track equipment, signals, track, or track structure, and roadbed at or exceeding the dollar damage threshold." Train *incidents* are defined as "events involving on-track railroad equipment [and non-train incidents arising from the operation of a railroad] that result in the reportable death and/or injury or illness of one or more persons, but do not result in damage at or beyond the damage threshold." The Modal Study, because "damage to casks containing spent nuclear fuel will necessarily involve severe accidents" (hence, substantial damage), used only "train accidents" to form the basis for developing the conditional probabilities of accident severities.

As with motor carrier operations, the constancy of the definition of a train accident is important in establishing confidence in the impact. For rail accidents the transportation environment has not changed dramatically over the years of data collection, and the definition of *accident* has remained essentially unchanged (with adjustments for inflation). The constancy of the definition provides confidence that the distribution of severity for reported accidents has remained relatively the same—low-consequence, limited-damage accidents are the most common and high-consequence, highly energetic accidents are rare, and their proportions have remained about the same. Changes in the rail transportation environment, as in safety and operations technology (for example, shelf-type couplers and tankcar head protection), have resulted in lower accident rates (per railcar-kilometer of travel) and, in some cases, less severe accidents. However, because the definition of *accident* has not changed appreciably, the changes that have occurred are not the kind that would greatly affect the relative proportions of minor and severe accidents.

Reporting and Definitions for Marine Casualties and Incidents

As with the regulations governing the reporting of motor carrier and rail accidents, U.S. law (46 USC 6101-6103) requires operators to report marine casualties and incidents if there are injuries, fatalities, or property damage. In addition, the law requires the reporting of significant harm to the environment.

MARINE CASUALTY AND INCIDENT
(46 USC 6101-6103)

Criteria have been established for the required reporting (by vessel operators and owners) of marine casualties and incidents involving all United States flag vessels occurring anywhere in the world and any foreign flag vessel operating on waters subject to the jurisdiction of the United States. An incident must be reported within five days if it results in:

- The death of an individual
- Serious injury to an individual
- "Material" loss of property (threshold not specified; previously was $25,000)
- Material damage affecting the seaworthiness or efficiency of the vessel
- Significant harm to the environment

The states collect casualty data for incidents occurring in navigable waterways within their borders, and there is a uniform state marine casualty reporting system for transmitting these reports to Federal jurisdiction (the U. S. Coast Guard). Coast Guard Headquarters receives quarterly extracts of the Marine

Safety Information System developed from these sources. This system is a network data base into which Coast Guard investigators enter cases at each marine safety unit. The analysis uses a Relational Database Management System. The Coast Guard Office of Investigations and Analysis compiles and processes the casualty reports into the formats and partitioned data sets that comprise the Marine Safety Information System data base, which includes maritime accidents, fatalities, injuries, and pollution spills dating to 1941 (however, the file is complete only from about 1991 to the present).

Hazardous Material Transportation Accident and Incident Reporting and Definitions

Radioactive material is a subset of the more general term *hazardous material*, which includes commodities such as gasoline and chemical products. The U.S. Department of Transportation Office of Hazardous Materials estimates that there are more than 800,000 hazardous materials shipments per day, of which about 7,700 shipments contain radioactive materials.

Hazardous materials transportation regulations (49 CFR 171) contain no distinction between an *accident* and an *incident*, and *incident* is the term used to describe situations that must be reported. Hazardous materials regulations (49 CFR 171.15) require the reporting of incidents if:

- A person is killed
- A person receives injuries requiring hospitalization
- The estimated property damage is greater than $50,000
- An evacuation of the public occurs lasting one or more hours
- One or more major transportation arteries are closed or shutdown for one or more hours
- The operational flight pattern or routine of an aircraft is altered
- Fire, breakage, spillage, or suspected radioactive contamination occurs involving shipment of radioactive material
- Fire, breakage, spillage, or suspected contamination occurs involving shipment of infectious agents
- There has been a release of a marine pollutant in a quantity exceeding 450 liters (about 120 gallons) for liquids or 400 kilograms (about 880 pounds) for solids
- There is a situation that, in the judgement of the carrier, should be reported to the U.S. Department of Transportation even though it does not meet the above criteria

These criteria apply to loading, unloading, and temporary storage, as well as to transportation. The criteria involving infectious agents or aircraft are unlikely to be used for spent nuclear fuel or high-level radioactive waste shipments. Based on these criteria, reportable motor vehicle and rail transportation situations are far more exclusionary than hazardous material situations.

Carriers (not law enforcement officials) are required to report hazardous materials incidents to the U.S. Department of Transportation. These reports are compiled in the Hazardous Materials Incident Report data base. In addition, U.S. Nuclear Regulatory Commission regulations (20 CFR 20.2201, 20.2202, 20.2203) require the reporting of a loss of radioactive materials, exposure to radiation, or release of radioactive materials.

Sandia National Laboratories maintains the Radioactive Materials Incident Report (RMIR) data base, which contains incident reports from the Hazardous Materials Incident Report data base that involve radioactive material. In addition, RMIR contains data from the U.S. Nuclear Regulatory Commission, state radiation control offices, the DOE Unusual Occurrence Report data base, and media coverage of radioactive materials transportation incidents. DOE (1995, pages I-117) and McClure and Fagan (1998, all) discuss historic incidents involving spent nuclear fuel that are reported in RMIR as well as incidents that took place prior to the existence of this data base. RMIR characterizes incidents in three categories: transportation accidents, handling accidents, and reported incidents. However, the definitions of these categories are not consistent with the definitions used in other U.S. Department of Transportation data bases. For example, from 1971 through 1998, RMIR lists one transportation accident involving a loaded rail shipment of spent nuclear fuel. However, based on current Federal Railroad Administration reporting requirements, this occurrence probably would be listed as a grade-crossing incident, not an accident. For this reason and because of the small number of occurrences in the data base involving spent nuclear fuel, the EIS analysis did not use RMIR to estimate transportation accident rates.

J.1.4.2.3.2 Accident Rates for Transportation by Heavy-Combination Truck, Railcar, and Barge in the United States. Saricks and Tompkins (1999, all) developed estimates of accident rates for heavy-combination trucks, railcars, and barges based on data available for 1994 through 1996. The estimates provide an update for accident rates published in 1994 (Saricks and Kvitek 1994, all) that reflected rates from almost a decade earlier.

Rates for Accidents in Interstate Commerce for Heavy-Combination Trucks

Saricks and Tompkins (1999, all) developed basic descriptive statistics for state-specific rates of accidents involving interstate-registered combination trucks for 1994, 1995, and 1996. The accident rate over all road types for 1994 was 2.98×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3a); for 1995 it was 2.97×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3b); and for 1996 it was 3.46×10^{-7} accident per truck-kilometer (Saricks and Tompkins, 1999, Table 3c). The composite mean from 1994 through 1996 was 3.21×10^{-7} accident per truck-kilometer.

During the 24 years of the Proposed Action, the *mostly legal-weight truck* national transportation scenario would involve as many as 50,000 truck shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in Saricks and Tompkins (1999, Table 4), the transportation analysis estimated that those shipments could involve as many as 40 accidents. During the same period, the *mostly rail* scenario would involve about 2,600 truck shipments, and the analysis estimated that as many as two accidents could occur during these shipments. More than 99 percent of these accidents would not generate forces capable of causing functional damage to the casks, and would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask.

Rates for Freight Railcar Accidents

Results for accident rates for freight railcar shipments from Saricks and Tompkins (1999, all), show that domestic rail freight accidents, fatalities, and injuries on Class 1 and 2 railroads have remained stable or declined slightly since the late 1980s. Based on data from 1994 through 1996, these rates are 5.39×10^{-8}, 8.64×10^{-8}, and 1.05×10^{-8} per railcar-kilometer, respectively (Saricks and Tompkins, 1999, Table 6). This conclusion is based on applying denominators that do *not* include train and car kilometers for intermodal shipments (containers and trailers-on-flatcar) not loaded by the carriers themselves. Thus, the actual denominators are probably higher and the rates consequently lower, by about 20 percent.

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario would involve as many as 11,000 rail shipments of spent nuclear fuel and high-level radioactive waste. Based on the data in Saricks and Tompkins (1999, Table 6), the analysis estimated that these shipments could involve one or two accidents. More than 99 percent of these accidents would not generate forces capable of causing functional damage to the cask; these accidents would have no radiological consequences. A small fraction of the accidents could generate forces capable of damaging the cask. For the *mostly legal-weight truck* scenario, rail accidents would be unlikely during the 300 railcar shipments of naval spent nuclear fuel.

Rates for Barge Accidents

Waterway results show a general improvement over mid-1980s rates. The respective rates for 450-metric-ton (500-ton) shipments for waters internal to the coast (rivers, lakes, canals, etc.) for accident and incident involvements and fatalities were 1.68×10^{-6} and 8.76×10^{-9} per shipment-kilometer, respectively (Saricks and Tompkins 1999, Table 8b). Rates for lake shipping were lower—2.58×10^{-7} and 0 per shipment-kilometer, for accidents and incidents and for fatalities, respectively. Coastal casualty involvement rates have risen in comparison to the data recorded about 10 years ago, and are comparable to rates for internal waters—5.29×10^{-7} and 8.76×10^{-9} per shipment-kilometer (Saricks and Tompkins 1999, Table 9b).

During the 24 years of the Proposed Action, the *mostly rail* national transportation scenario could involve the use of barges to ship spent nuclear fuel from 14 commercial sites. Based on the data in Saricks and Tompkins (1999, all), the analysis estimated that less than one accident could occur during such shipments. A barge accident severe enough to cause measurable damage to a shipping cask would be highly unlikely.

Rates for Safe Secure Trailer Accidents

DOE uses safe secure trailers to transport hazardous cargoes in the continental United States. The criteria used for reporting accidents involving these trailers are damage in excess of $500, a fire, a fatality, or damage sufficient for the trailer to be towed. From 1975 through 1998, 14 accidents involved safe secure trailers over about 54 million kilometers (about 34 million miles) of travel, which yields a rate of 2.6×10^{-7} accident per kilometer (4.2×10^{-7} per mile). This rate is comparable to the rate estimated by Saricks and Tompkins (1999, Table 4) for heavy combination trucks, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile).

J.1.4.2.3.3 Accident Data Provided by the States of Nevada, California, South Carolina, Illinois, and Nebraska. In May 1998, DOE requested the 48 contiguous states to provide truck and rail transportation accident data for use in this EIS. Five states responded – Nevada, California, Illinois, Nebraska, and South Carolina (Denison 1998, all; Caltrans 1997, all; Wort 1998, all; Kohles 1998, all; SCDPS 1997, all**)**. No states provided rail information.

- *Nevada.* Nevada provided a highway accident rate of 1.1×10^{-6} accident per kilometer (1.8×10^{-6} per mile) for interstate carriers over all road types. This is higher than the accident rate estimated by Saricks and Tompkins (1999, Table 4); 2.5×10^{-7} accident per kilometer (3.9×10^{-7} per mile) for heavy trucks over all road types in Nevada from 1994 to 1996.

  The definition of *accident* used in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in Nevada the accident criteria are fatality, injury, or $750 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition would reduce the accident rate from 1.1×10^{-6} to about 4.1×10^{-7} accident per kilometer (1.8×10^{-6} to 6.7×10^{-7} per mile). The radiological accident risk in Nevada for the mostly legal-weight truck scenario would increase over 24 years from 0.0002 latent cancer fatality to about 0.0005 latent cancer fatality (a likelihood of 5 in 10,000 of one latent cancer fatality) if the accident rate reported by Saricks and Tompkins for Nevada were replaced by the rate of 4.1×10^{-7} per kilometer. Thus, the impacts of the rate for accidents involving large trucks on Nevada highways reported by Nevada (Denison 1998, all) would be comparable to the impacts derived using rate estimated by Saricks and Tompkins.

- *California.* California responded with highway accident rates that included all vehicles (cars, buses, and trucks). The accident rate for Interstate highways was 4.2×10^{-7} accident per kilometer (6.8×10^{-7} per mile) for all vehicles in 1996. This rate is higher than the accident rate estimated by Saricks and Tompkins (1999, Table 4), 1.6×10^{-7} accident per kilometer (2.6×10^{-7} per mile) for heavy trucks on California interstate highways from 1994 to 1996.

  The definition of *accident* in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in California the accident criteria are fatality, injury, or $500 property damage. Based on national data from FHWA (1997, page 2) and FHWA (1998, pages 1 and 2**),** using the Federal definition would reduce the accident rate from 4.2×10^{-7} to about 1.6×10^{-7} accident per kilometer (6.8×10^{-7} to 2.6×10^{-7} per mile). In addition, the rate provided by California was for all vehicles. Based on national data from the U.S. Department of Transportation Bureau of Transportation Statistics, using the accident rate for large trucks would reduce the all-vehicle accident rate from 1.6×10^{-7} to about 1.3×10^{-7} accident per kilometer (2.6×10^{-7} to 2.1×10^{-7} per mile) for large trucks. This rate is slightly less than the rate estimated by Saricks and Tompkins (1999, Table 4**)**, 1.6×10^{-7} accident per kilometer.

- *Illinois.* Illinois provided highway data for semi-trucks from 1991 through 1995 over all road types. Over this period, the accident rate was 1.8×10^{-6} accident per kilometer (2.9×10^{-6} per mile). From 1994 through 1996, Saricks and Tompkins (1999, all) estimated an accident rate of 3.0×10^{-7} accident per kilometer (4.8×10^{-7} per mile) for heavy trucks over all road types in Illinois.

  The definition of *accident* used in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in Illinois the accident criteria are fatality, injury, or $500 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition would reduce the accident rate from 1.8×10^{-6} to about 6.7×10^{-7} accident per kilometer (2.9×10^{-6} to 1.1×10^{-6} per mile). This rate is comparable to the rate estimated by Saricks and Tompkins (1999, all).

- *Nebraska.* Nebraska provided a highway accident rate of 2.4×10^{-7} accident per kilometer (3.8×10^{-7} per mile) for 1997. Nebraska did not specify if the rate was for interstate highways, but it is for interstate truck carriers. This rate is slightly less than the accident rate estimated by Saricks and Tompkins (1999, all) for Nebraska interstates, 3.2×10^{-7} accident per kilometer (5.1×10^{-7} per mile) for heavy trucks from 1994 through 1996.

- *South Carolina.* South Carolina responded with highway accident rates that included all types of tractor/trailers (for example, mobile homes, semi-trailers, utility trailers, farm trailers, trailers with boats, camper trailers, towed motor homes, petroleum tankers, lowboy trailers, auto carrier trailers, flatbed trailers, and twin trailers). The rate was 8.3×10^{-7} accident per kilometer (1.3×10^{-6} per mile), for all road types. [This is higher than the accident rate estimated by Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile) for heavy trucks on all road types in South Carolina from 1994 through 1996].

  The definition of *accident* in Saricks and Tompkins (1999, page 4) is the Federal definition (fatality, injury, or tow-away); in South Carolina the accident criteria are fatality, injury, or $1,000 property damage. Based on national data from the U.S. Department of Transportation Office of Motor Carrier Information Analysis (FHWA 1997, page 2; FHWA 1998, pages 1 and 2), using the Federal definition of an accident would reduce the accident rate from 8.3×10^{-7} to about 3.1×10^{-7} accident per kilometer (1.3×10^{-6} to 5.0×10^{-7} per mile), which is slightly less than the rate estimated by Saricks and Tompkins (1999, all), 4.7×10^{-7} accident per kilometer (7.6×10^{-7} per mile). In addition, the accident rate estimated by Saricks and Tompkins (1999, all) was based on Motor Carrier Management Information System vehicle configuration codes 4 through 8 (truck/trailer, bobtail, tractor/semi-trailer, tractor/double, and tractor/triple), while the rate obtained from South Carolina included all truck/trailer combinations. Including all of the combinations tends to increase accident rates; for example, light trucks have higher accident rates than heavy trucks (BTS 1999, Table 3-22).

DOE evaluated the effect of using the data provided by the five states on radiological accident risk for the mostly legal-weight truck national transportation scenario. If the data used in the analysis for the five states (Saricks and Tompkins 1999, Table 4) were replaced by the data provided by the states with the adjustments discussed, the change in the resulting estimate of radiological accident risk would be small, increasing from 0.067 to 0.071 latent cancer fatality. Using the unadjusted data provided by those states would result in an increase in accident risk from 0.067 to 0.093 latent cancer fatality.

J.1.4.2.4 *Transportation Accidents Involving Nonradioactive Hazardous Materials*

The analysis of impacts of transportation accidents involving the transport of nonradioactive hazardous materials to and from Yucca Mountain used information presented in two U.S. Department of Transportation reports (DOT 1998b, Table 1; BTS 1996, page 43) on the annual number of hazardous materials shipments in the United States and the number of deaths caused by hazardous cargoes in 1995. In total, there are about 300 million annual shipments of hazardous materials; only a small fraction involve radioactive materials. In 1995, 6 fatalities occurred because of hazardous cargoes. These data suggest a rate of 2 fatalities per 100 million shipments of hazardous materials. DOE anticipates about 40,000 shipments of nonradioactive hazardous materials (including diesel fuel and laboratory and industrial chemicals) to and from the Yucca Mountain site during construction, operation and monitoring, and closure of the repository. Assuming that the rate for fatalities applies to the transportation of nonradioactive hazardous materials to and from Yucca Mountain, DOE does not expect fatalities from 40,000 shipments of these materials.

J.2 Evaluation of Rail and Intermodal Transportation Options

DOE could use several modes of transportation to ship spent nuclear fuel from the 77 sites. Legal-weight trucks could be used to transport spent nuclear fuel and high-level radioactive waste contained in truck casks that would weigh approximately 22,500 kilograms (25 tons) when loaded. For sites served by railroads, rail casks placed on railcars could be used to ship directly to the Yucca Mountain site if a branch rail line was constructed in Nevada or to ship to an intermodal transfer station in Nevada if heavy-haul trucks were used.

For sites not served by a railroad that nonetheless have the capability to load rail casks, DOE could use heavy-haul trucks or, for sites located on navigable waterways, barges to transport the casks between the generating sites and nearby railheads.

For rail shipments, DOE could request the railroads provide dedicated trains to transport casks from sites to a destination in Nevada or could deliver railcars with loaded casks to the railroads as general freight for delivery in Nevada.

J.2.1 IMPACTS OF THE SHIPMENT OF COMMERCIAL SPENT NUCLEAR FUEL BY BARGE AND HEAVY-HAUL TRUCK FROM 19 SITES NOT SERVED BY A RAILROAD

An alternative to truck or rail transport of commercial spent nuclear fuel, barge transportation, was evaluated. Nineteen commercial sites that have the capability to handle and load rail casks are not served by a railroad. Accordingly, under the mostly rail transportation scenario the 19 sites were assumed to use heavy-haul trucks to move the rail casks to nearby railheads. However, because 14 of the sites are on navigable waterways (see Figure J-9), some could use barges to ship to nearby railheads. The following sections present the analysis of impacts of using barges and compares these impacts from one of the fourteen sites located on a navigable waterway (Turkey Point) to the impacts based on the use of heavy-haul trucks and legal-weight truck. The analysis assumed that all five of the DOE sites would have railroad service.

Unlike previous sections, where impacts were presented for all shipments by mode (mostly legal-weight truck and mostly rail), impacts are reported on a per shipment basis and compared on that basis to shipments via heavy-haul truck and legal-weight truck for the same reactor site.

J.2.1.1 Routes for Barges and Heavy-Haul Trucks

The heavy-haul truck-to-railhead distances for the 19 sites range from about 6 to 75 kilometers (4 to 47 miles). Routing for heavy-haul trucks was estimated using the HIGHWAY computer code (Johnson et al. 1993a, all). The INTERLINE computer code (Johnson et al. 1993b, all) was used to generate route-specific distances that would be traveled by barges. The resulting estimates for route lengths for barges and heavy-haul trucks are listed in Table J-26. Table J-27 lists the number of shipments from each site.

J.2.1.2 Analysis of Incident-Free Impacts for Barge and Heavy-Haul Truck Transportation

J.2.1.2.1 *Radiological Impacts of Incident-Free Transportation*

This section compares the radiological and nonradiological impacts to populations and maximally exposed individuals of incident-free transportation of spent nuclear fuel from one commercial spent nuclear fuel site (Turkey Point) for:

- Shipments using heavy-haul trucks to the nearest railhead and then to the Nevada Caliente node by rail and finally to the Yucca Mountain site by rail using the Caliente-Chalk Mountain corridor.
- Shipments using barge to a nearby railhead (Port of Miami for the Turkey Point site) and then to the Nevada Caliente node by rail and finally to the Yucca Mountain site by rail using the Caliente-Chalk Mountain corridor.
- Shipments using legal-weight trucks to the Yucca Mountain site.

The radiological impacts of intermodal transfers at the interchange from heavy-haul trucks to railcars or barges to railcars were included in the analysis. Workers would be exposed to radiation from casks during transfer operations. However, because the transfers would occur in terminals and berths that are remote from public access, public exposures would be small. Impacts of constructing intermodal transfer facilities were not included because intermodal transfers were assumed to take place at existing facilities.

The analysis assumed that heavy-haul trucks, though they would be slower moving vehicles, would result in the same types of impacts as, although somewhat higher than, an equal number of legal-weight truck shipments over the same routes. Because travel distances to nearby railheads would be short, impacts of

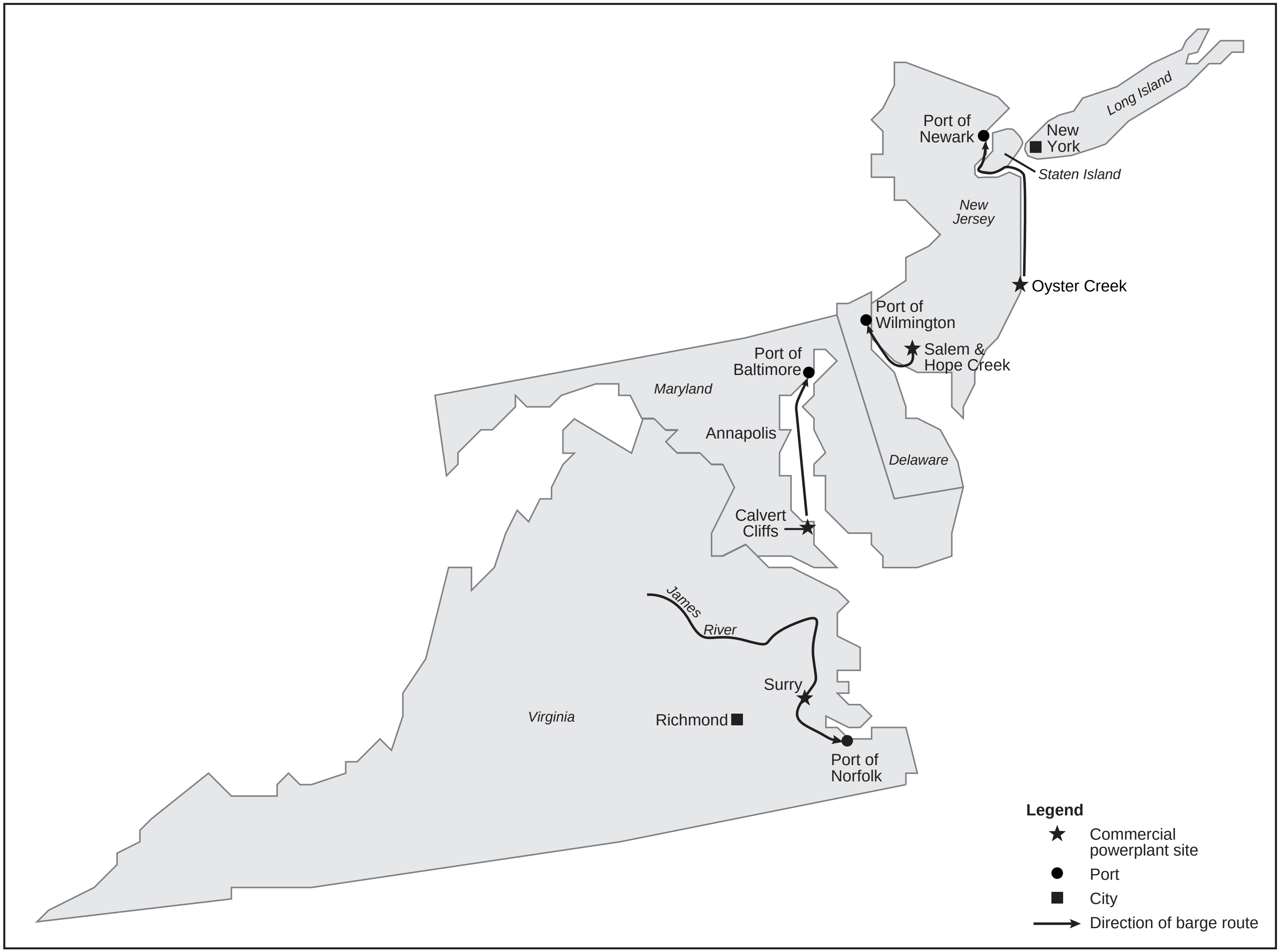


Figure J-9. Routes for barges from sites to nearby railheads (page 1 of 3).

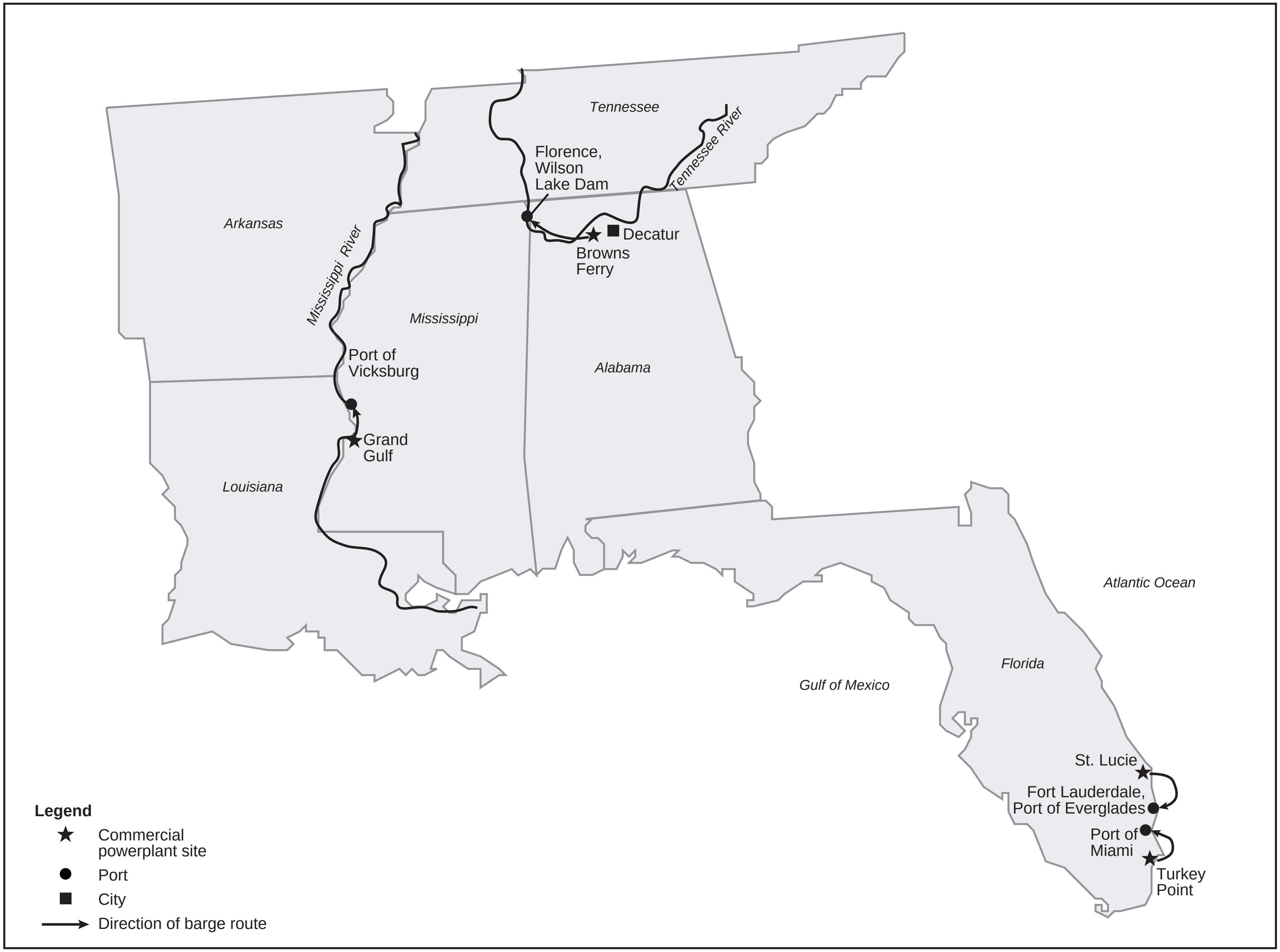


Figure J-9. Routes for barges from sites to nearby railheads (page 2 of 3).

Figure J-9. Routes for barges from sites to nearby railheads (page 3 of 3).

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers)[a,b] (page 1 of 2).

Site (intermodal rail node)[c]	State	Destination	Rail transportation Total[d]	Rural	Suburban	Urban	Barge transportation Total[d]	Rural	Suburban	Urban
Browns Ferry NP[e]	AL	Apex	3,596	3,269	281	46	57	52	5	0
		Caliente	3,423	3,095	281	46	57	52	5	0
		Beowawe	3,278	2,990	254	34	57	52	5	0
		Jean	3,678	3,333	293	51	57	52	5	0
Diablo Canyon NP	CA	Apex	644	420	124	100	143	143	0	0
		Caliente	817	594	124	100	143	143	0	0
		Beowawe	1,439	1,005	291	141	143	143	0	0
		Jean	562	355	112	94	143	143	0	0
St. Lucie NP	FL	Apex	5,203	4,293	812	97	140	50	52	39
		Caliente	5,029	4,119	812	97	140	50	52	39
		Beowawe	4,885	4,014	784	86	140	50	52	39
		Jean	5,284	4,358	823	103	140	50	52	39
Turkey Point NP	FL	Apex	5,245	4,296	820	127	54	53	0	1
		Caliente	5,071	4,123	820	127	54	53	0	1
		Beowawe	4,927	4,017	793	116	54	53	0	1
		Jean	5,326	4,361	832	133	54	53	0	1
Calvert Cliffs NP	MD	Apex	4,344	3,558	645	140	99	98	2	0
		Caliente	4,170	3,385	645	140	99	98	2	0
		Beowawe	4,026	3,279	618	129	99	98	2	0
		Jean	4,425	3,623	657	145	99	98	2	0
Palisades NP	MI	Apex	3,375	2,895	391	90	256	256	0	0
		Caliente	3,202	2,722	391	90	256	256	0	0
		Beowawe	3,058	2,616	363	78	256	256	0	0
		Jean	3,457	2,960	402	95	256	256	0	0
Grand Gulf NP	MS	Apex	3,686	3,355	291	39	51	51	0	0
		Caliente	3,512	3,181	291	39	51	51	0	0
		Beowawe	3,368	3,076	264	28	51	51	0	0
		Jean	3,767	3,419	303	44	51	51	0	0
Cooper NP	NE	Apex	2,345	2,193	119	33	117	100	16	1
		Caliente	2,171	2,020	119	33	117	100	16	1
		Beowawe	2,027	1,914	92	21	117	100	16	1
		Jean	2,426	2,258	130	38	117	100	16	1
Salem/Hope Creek NP	NJ	Apex	4,423	3,410	818	194	30	30	0	0
		Caliente	4,250	3,236	818	194	30	30	0	0
		Beowawe	4,106	3,131	791	183	30	30	0	0
		Jean	4,505	3,475	830	200	30	30	0	0
Oyster Creek NP	NJ	Apex	4,532	3,371	933	227	130	77	36	17
		Caliente	4,358	3,198	933	227	130	77	36	17
		Beowawe	4,214	3,092	906	216	130	77	36	17
		Jean	4,613	3,436	944	232	130	77	36	17
Surry NP	VA	Apex	4,583	3,982	532	68	71	60	8	3
		Caliente	4,409	3,809	532	68	71	60	8	3
		Beowawe	4,265	3,703	505	57	71	60	8	3
		Jean	4,664	4,047	544	73	71	60	8	3
Kewaunee NP	WI	Apex	3,180	2,789	312	79	293	285	2	7
		Caliente	3,007	2,616	312	79	293	285	2	7
		Beowawe	2,863	2,510	285	68	293	285	2	7
		Jean	3,262	2,854	323	84	293	285	2	7
Point Beach NP	WI	Apex	3,180	2,789	312	79	301	293	2	7
		Caliente	3,007	2,616	312	79	301	293	2	7
		Beowawe	2,863	2,510	285	68	301	293	2	7
		Jean	3,262	2,854	323	84	301	293	2	7
Callaway NP	MO	Apex	2,796	2,625	140	31	--[f]	--	--	--
HH – 18.5 kilometers		Caliente	2,624	2,452	140	31	--	--	--	--
		Beowawe	2,491	2,358	113	20	--	--	--	--
		Jean	2,878	2,689	151	37	--	--	--	--
Fort Calhoun NP	NE	Apex	2,301	2,177	102	21	--	--	--	--
HH – 6.0 kilometers		Caliente	2,129	2,005	102	21	--	--	--	--
		Beowawe	1,996	1,911	75	10	--	--	--	--
		Jean	2,383	2,242	114	27	--	--	--	--

Table J-26. National transportation distances from commercial sites to Nevada ending rail nodes (kilometers)[a,b] (page 2 of 2).

Site (intermodal rail node)[c]	State	Destination	Rail transportation Total[d]	Rural	Suburban	Urban	Barge transportation Total[d]	Rural	Suburban	Urban
Peach Bottom NP[e]	PA	Apex	4,294	3,324	779	191	--[f]	--	--	--
HH – 58.9 kilometers		Caliente	4,121	3,151	779	191	--	--	--	--
		Beowawe	3,988	3,057	752	179	--	--	--	--
		Jean	4,375	3,388	790	196	--	--	--	--
Oconee NP	SC	Apex	4,247	3,651	534	61	--	--	--	--
HH – 17.5 kilometers		Caliente	4,074	3,479	534	61	--	--	--	--
		Beowawe	3,941	3,385	507	50	--	--	--	--
		Jean	4,328	3,716	546	66	--	--	--	--

a. To convert kilometers to miles, multiply by 0.62137.
b. Distances estimated using INTERLINE computer program.
c. Intermodal rail nodes selected for purpose of analysis. Source: TRW (1999a, all).
d. Totals might differ from sums of rural, suburban, and urban distances due to method of calculation and rounding.
e. NP = nuclear plant.
f. -- = the four sites that are not located on a navigable waterway.

Table J-27. Barge shipments and ports.

Plant name	State	Number of shipments: Proposed Action	Number of shipments: Modules 1 and 2	Barge ports assumed for barge-to-rail intermodal transfer
Browns Ferry 1	AL	176	253	Wilson L/D
Browns Ferry 3	AL	67	114	Wilson L/D
Diablo Canyon 1	CA	64	129	Port Huememe
Diablo Canyon 2	CA	59	149	Port Huememe
St. Lucie 2	FL	56	103	Port Everglades
Turkey Point 3	FL	56	80	Port of Miami
Turkey Point 4	FL	57	89	Port of Miami
Calvert Cliffs 1	MD	144	204	Port of Baltimore
Palisades	MI	70	70	Port of Muskegan
Grand Gulf 1	MS	79	154	Port of Vicksburg
Cooper Station	NE	103	159	Port of Omaha
Hope Creek	NJ	59	146	Port of Wilmington
Oyster Creek 1	NJ	87	87	Port of Newark
Salem 1	NJ	63	104	Port of Wilmington
Salem 2	NJ	57	112	Port of Wilmington
Surry 1	VA	102	128	Port of Norfolk
Kewaunee	WI	57	70	Port of Milwaukee
Point Beach 1	WI	90	102	Port of Milwaukee
Totals		**1,833**	**2,970**	

heavy-haul truck transportation would be much less than the impacts of national rail shipments. The analysis of impacts for barge shipments assumed the transport would employ commercial vessels operated by maritime carriers on navigable waterways and that these shipments would follow direct routing from the sites to nearby railheads. For both modes, intermodal transfers would be necessary to transfer rail casks to railcars.

Radiological impacts were estimated for workers and the general population. For heavy-haul truck shipments, workers included vehicle drivers and escorts. For barge shipments, the work crew included five members on board during travel and workers close to the shipping casks during inspections or intermodal transfers. The general population for truck shipments included persons within 800 meters (about 2,600 feet) of the road (offlink), persons sharing the road (onlink), and persons at stops. The general population for barging included persons within a range of 200 to 1,000 meters (about 660 to 3,300 feet) of the route, and persons at stops. On-link exposures to members of the public during barging were assumed to be small. Incident-free unit risk factors were developed to calculate occupational and general population collective doses. Table J-28 lists the unit risk factors for heavy-haul truck and barge shipments. The unit risk factors for heavy-haul truck shipments reflect the effects of slower operating speeds for those vehicles in comparison to those for legal-weight trucks.

Table J-28. Risk factors for incident-free heavy-haul truck and barge transportation of spent nuclear fuel and high-level radioactive waste.

		Incident free risk factors (person-rem per kilometer)[a]		
Mode	Exposure group	Rural	Suburban	Urban
Heavy-haul truck	*Occupational*	1.1×10^{-5}	1.1×10^{-5}	1.9×10^{-5}
	General population			
	Offlink[b]	7.3×10^{-8}	7.7×10^{-8}	8.3×10^{-8}
	Onlink[c]	1.1×10^{-4}	1.2×10^{-4}	5.5×10^{-4}
	Stops	1.9×10^{-4}	1.9×10^{-4}	1.9×10^{-4}
	Storage[d]	1.9×10^{-3}	1.9×10^{-3}	1.9×10^{-3}
	Totals	$\mathbf{2.2\times10^{-3}}$	$\mathbf{2.3\times10^{-3}}$	$\mathbf{2.7\times10^{-3}}$
Barge	*Occupational* [d]	9.4×10^{-7}	1.9×10^{-6}	4.8×10^{-6}
	General population			
	Offlink[b]	8.6×10^{-8}	1.7×10^{-7}	4.3×10^{-7}
	Onlink[c]	0.0	0.0	0.0
	Stops	5.4×10^{-3}	5.4×10^{-3}	5.4×10^{-3}
	Totals	$\mathbf{5.4\times10^{-3}}$	$\mathbf{5.4\times10^{-3}}$	$\mathbf{5.5\times10^{-3}}$

a. The methodology, equations, and data used to develop the unit dose factors are discussed in Madsen et al. (1986, all) and Neuhauser and Kanipe (1992, all). Cashwell et al. (1986, all) contains a detailed explanation of the use of unit factors.
b. Offlink general population included persons within 800 meters (about 2,600 feet) of the road or railway.
c. Onlink general population included persons sharing the road or railway.
d. The storage unit risk factor is only applied for heavy-haul truck shipments requiring an overnight stop.

Table J-29 lists the incident-free impacts on a per shipment basis from the Turkey Point nuclear power plant using the three shipment scenarios listed above. This is presented to compare the impacts on a per shipment basis using barge, heavy-haul truck or legal weight truck. Impacts of intermodal transfers are included in the results. Occupational impacts would include the estimated radiological exposures of security escorts.

Table J-29. Comparison of population doses and impacts from incident-free national transportation for heavy-haul-to-rail, barge-to-rail, and legal-weight truck options.[a,b]

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Involved worker			
Collective dose (person-rem)	0.15	0.13	0.32
Estimated LCFs[c]	0.00006	0.00005	0.00013
Public			
Collective dose (person-rem)	0.12	0.41	1
Estimated LCFs	0.00006	0.0002	0.0005
Maximally exposed individual	Impacts would be the same as those in Chapter 6, Tables 6-9 and 6-12		

a. Rail impacts are presented for the Caliente-Chalk Mountain rail implementing alternative.
b. Impacts presented on a per shipment basis for the Turkey Point site.
c. LCF = latent cancer fatality.

As indicated in Table J-29, differences in radiological impacts between the use of heavy-haul trucks and barges would be small. The impacts to maximally exposed individuals would be the same because both cases use the same assumptions for locations of such individuals in relation to shipments and times of exposure.

J.2.1.2.2 *Nonradiological Impacts of Incident-Free Transportation (Vehicle Emissions)*

Table J-30 compares the estimated number of fatalities from vehicle emissions from shipments, assuming the use of heavy-haul trucks or barges to ship to nearby railheads.

Table J-30. Population health impacts from vehicle emissions during incident-free national transportation for mostly legal-weight truck scenario.[a]

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Estimated fatalities	0.00004	0.00004	0.00003

a. Impacts are presented on a per shipment basis for the Turkey Point site.

J.2.1.3 Analysis of Impacts of Accidents for Barge and Heavy-Haul Truck Transportation

J.2.1.3.1 *Radiological Impacts of Accidents*

The analysis of risks from accidents during heavy-haul truck, rail, and legal-weight truck transport of spent fuel and high-level radioactive waste used the RADTRAN4 computer code (Neuhauser and Kanipe 1992, all) and the analysis approach discussed in Section J.1.4.2. The analysis of risks due to barging used the same methodology with the exception of conditional probabilities. For barge shipments, the conditional accident probabilities (Table J-31) for each cask response category were based on a review of other barge accident analyses.

Table J-31. Conditional probabilities for barge transportation.

Severity category	1	2	3	4	5	6
Conditional probability	0.93794	0.005	0.000	0.057	0.000051	0.0000058

When radioactive material is shipped by barge, it is possible to have both water and land contamination. The analysis assumed that airborne releases could occur in accidents involving barges. Any portion of a release plume over water would result in water contamination. Thus, there are two mechanisms for contaminating water and one, the airborne release, for contaminating land surfaces.

For accident scenarios that result in releases of radioactive material, part of the plume would be deposited on water and part on land. For coastal and lake shipping, the analysis assumed that, 50 percent of the time, the plume would be entirely deposited on water. For the other 50 percent, the analysis assumed that the accident would occur about 200 meters (660 feet) from the shore and any material deposited in the first 200 meters would be into water. The analysis used the methods used by the RISKIND computer program (Yuan et al. 1995 all) to estimate plume depletion into water for D stability and a wind speed of 3 meters per second. For these conditions, about 20 percent of the plume would be depleted in the first 200 meters. Based on this information, the analysis assumed that for coastal and lake shipping, 60 percent of the plume would be deposited on water and for river transport only 20 percent of the release would occur over water.

The analysis accommodated this split by allocating 60 percent of coastal and lake shipping to what was called a “water” state and the remaining 40 percent to an adjoining state (Florida in the case of Turkey

Point). For river transport, 20 percent of the mileage was allocated to the water state representing the river and the remaining 80 percent of the mileage was allocated to the adjacent state (Mississippi in the case of Browns Ferry).

The dose from plume release to water was limited to an ingestion dose. The transfer coefficients that were used in the calculation are listed in Table J-32. The selection of isotopes and the transfer coefficients was based on models used in the Foreign Spent Nuclear Fuel EIS (DOE 1996a, page E-126). The same water uptake models were used. Both the freshwater and ocean models considered fish consumption. The freshwater model included irrigation and domestic water consumption by both the general population and livestock. The ocean model included uptake from eating shellfish.

Table J-32. Food transfer factors used in the barge analysis.

Isotope	Ocean release	Freshwater release
Hydrogen-3 (tritium)		0.000020
Niobium-95	0.080	
Ruthenium-106	0.00014	
Cesium-134	0.00037	0.000022
Cesium-137	0.00037	0.000022

In addition, the analysis of barge accident risks used the following assumptions:

- Release fractions that determine the source term for dispersion to the waterway are the same as those developed for airborne release scenarios

For freshwater river systems, the analysis assessed the following exposure pathways:

- Drinking water
- Ingestion of fish by humans
- Ingestion of irradiated foods
- Shoreline deposits
- External irradiation from immersion during swimming

For marine coastal systems, the following exposure pathways were assessed:

- Ingestion of fish and invertebrates by humans
- External irradiation from shoreline deposits
- External irradiation from immersion during swimming

Route-specific collective doses were calculated using population distributions along the routes developed from 1990 Census data. As an example, Table J-33 presents the dose risk per shipment for the Turkey Point nuclear power plant.

Table J-33. Accident risks for shipping spent nuclear fuel from Turkey Point.

Category	Heavy-haul to rail	Barge to rail	Legal-weight truck
Dose risk (person-rem)	0.0038	0.0019	0.0023
Dose risk (LCF)[a]	0.000002	0.0000009	0.000001
Traffic fatalities	0.00039	0.00039	0.00011

a. LCF = latent cancer fatality.

J.2.1.3.2 *Nonradiological Accident Risks*

The fatalities per shipment for heavy-haul truck, barge, and legal-weight truck transport from Turkey Point would be 3.9×10^{-4}, 3.9×10^{-4} and 1.1×10^{-4} , respectively.

J.2.1.3.3 *Maximum Reasonably Foreseeable Accidents*

With the relatively short barging distance relative to the rail distance traveled, the probability of a barge accident is much lower than the 1×10^{-7}-criteria used for accidents that are reasonably foreseeable.

J.2.2 EFFECTS OF USING DEDICATED TRAINS OR GENERAL FREIGHT SERVICE

The Association of American Railroads recommends that only special (dedicated) trains move spent nuclear fuel and certain other forms of radioactive materials (DOT 1998b, page 2-6). In developing its recommendation, the Association concluded that the use of special trains would provide operational (for railroads and shippers) and safety advantages over shipments that used general freight service. Notwithstanding this recommendation, the Department of Transportation study (DOT 1998b, all) compared dedicated and regular freight service using factors that measure impacts to overall public safety. The results of this study indicated that dedicated trains could provide advantages over regular trains for incident-free transportation but could be less advantageous for accident risks. However, available information does not indicate a clear advantage for the use of either dedicated trains or general freight service. Thus, DOE has not determined the commercial arrangements it would request from railroads for shipment of spent nuclear fuel and high-level radioactive waste. Table J-34 compares the dedicated and general freight modes. These comparisons are based on the findings of the Department of Transportation study and the Association of American Railroads.

J.3 Nevada Transportation

With the exceptions of the possible construction of a branch rail line or upgrade of highways for use by heavy-haul trucks and the construction of an intermodal transfer station, the characteristics of the transportation of spent nuclear fuel and high-level radioactive waste in Nevada would be similar to those for transportation in other states across the nation. Unless the State of Nevada designated alternative or additional preferred routes as prescribed under regulations of the Department of Transportation (49 CFR 397.103), Interstate System Highways (I-15) would be the preferred routes used by legal-weight trucks carrying spent nuclear fuel and high-level radioactive waste. Unless alternative or non-Interstate System routes have been designated by states, Interstate system Highways would also be the preferred routes used by legal-weight trucks in other states during transit to Nevada.

In Nevada as in other states, rail shipments would, for the most part, be transported on mainline tracks of major railroads. Operations over a branch rail line in Nevada would be similar to those on a mainline railroad, except the frequency of train travel would be much lower. Shipments in Nevada that used heavy-haul trucks would use Nevada highways in much the same way that other overdimensional, overweight trucks use the highways along with other commercial vehicle traffic.

In some cases State-specific assumptions were used to analyze human health and safety impacts in Nevada. A major difference would be that much of the travel in the State would be in rural areas where population densities are much lower than those of many other states. Another difference would be for travel in an urban area in the state. The most populous urban area in Nevada is the Las Vegas metropolitan area, which is also a major resort area with a high percentage of nonresidents. The analysis also addressed the channeling of shipments from the commercial and DOE sites into the transportation arteries in the southern part of the State. Finally, the analysis addressed the commuter and commercial

Table J-34. Comparison of general freight and dedicated train service.

Attribute	General freight	Dedicated train
Overall accident rate for accidents that could damage shipping casks	Same as mainline railroad accident rates	Expected to be lower than general freight service because of operating restrictions and use of the most up-to-date railroad technology.
Grade crossing, trespasser, worker fatalities	Same as mainline railroad rates for fatalities	Uncertain. Greater number of trains could result in more fatalities in grade crossing accidents. Fewer stops in classification yards could reduce work related fatalities and trespasser fatalities.
Security	Security provided by escorts required by NRC[a] regulations	Security provided by escorts required by NRC regulations; fewer stops in classification yards than general freight service.
Incident-free dose to public	Low, but more stops in classification yards than dedicated trains. However, classification yards would tend to be remote from populated areas.	Lower than general freight service. Dedicated trains could be direct routed with fewer stops in classification yards for crew and equipment changes.
Radiological risks from accidents	Low, but greater than dedicated trains	Lower than general freight service because operating restrictions and equipment could contribute to lower accident rates and reduced likelihood of maximum severity accidents.
Occupational dose	Duration of travel influences dose to escorts	Shorter travel time would result in lower occupational dose to escorts.
Utilization of resources	Long cross-country transit times could result in least efficient use of expensive transportation cask resources; best use of railroad resources; least reliable delivery scheduling; most difficult to coordinate state notifications.	Direct through travel with on-time deliveries would result in most efficient use of cask resources; least efficient use of railroad resources. Railroad resource demands from other shippers could lead to schedule and throughput conflicts. Easiest to coordinate notification of state officials.

a. NRC = U.S. Nuclear Regulatory Commission.

travel that would occur on highways in the southern part of the State as a consequence of the construction, operation and monitoring, and closure of the proposed repository.

This section presents information specific to Nevada that DOE used to estimate impacts for transportation activities that would take place in the State. It includes results for cumulative impacts that would occur in Nevada for transportation associated with Inventory Modules 1 and 2.

J.3.1 TRANSPORTATION MODES, ROUTES, AND NUMBER OF SHIPMENTS

J.3.1.1 Routes in Nevada for Legal-Weight Trucks

The analysis of impacts that would occur in Nevada used the characteristics of (1) highways in Nevada that would be used for shipments of spent nuclear fuel and high-level radioactive waste by legal-weight trucks, (2) rail routes from the border to rail nodes where the implementing alternatives would connect, and (3) rail corridors and highway routes analyzed for the rail and heavy-haul truck implementing alternatives in the State.

Figure J-10 shows the routes in Nevada that legal-weight trucks would use unless the State designated alternative or additional preferred routes. The figure shows estimates for the number of legal-weight truck shipments that would travel on each route segment for the mostly legal-weight truck and mostly rail transportation scenarios. The inset on Figure J-10 shows the proposed Las Vegas Beltway and the routes DOE anticipates legal-weight trucks traveling to the repository would use.

J.3.1.2 Routes in Nevada for Transporting Rail Casks

The rail and heavy-haul truck implementing alternatives for transportation in Nevada include five possible rail corridors and five possible routes for heavy-haul trucks; the corridors and routes for these implementing alternatives are shown in Figures J-11 and J-12. These figures also show the estimated number of rail shipments that would enter the State on mainline railroads. These numbers indicate shipments that would arrive from the direction of the bordering state for each of the implementing alternatives for the mostly rail transportation scenario.

Table J-35 lists the total length and cumulative distance in rural, suburban, and urban population zones in the State of Nevada used to analyze impacts of the implementing alternatives. Table J-36 lists the total population that lives within 800 meters (0.5 mile) of rail lines in Nevada. The estimated population that would live along each branch rail line was based on population densities along existing mainline railroads in Nevada.

Nevada Heavy-Haul Truck Scenario

Tables J-37 through J-41 summarize the road upgrades for each of the five possible routes for heavy-haul trucks that DOE estimates would be needed before routine use of a route to ship casks containing spent nuclear fuel and high-level radioactive waste.

Nevada Rail Corridors

Under the mostly rail scenario, DOE could construct and operate a branch rail line in Nevada. Based on the studies listed below, DOE has narrowed its consideration for a new branch rail line to five potential rail corridors—the Carlin, Caliente, Caliente-Chalk Mountain, Jean, and Valley Modified routes. DOE identified the five rail corridors through a process of screening potential rail alignments that it had studied in past years. Several studies evaluated rail options.

- The *Feasibility Study for Transportation Facilities to Nevada Test Site* study (Holmes & Narver 1962, all) determined the technical and economic feasibility of constructing and operating a railroad from Las Vegas to Mercury.

- The *Preliminary Rail Access Study* (Tappen and Andrews 1990, all) identified 13 and evaluated 10 rail corridor alignment options. This study recommended the Carlin, Caliente, and Jean corridors for detailed evaluation.

- *The Nevada Railroad System: Physical, Operational, and Accident Characteristics* (DOE 1991, all) described the operational and physical characteristics of the current Nevada railroad system.

- The *High Speed Surface Transportation Between Las Vegas and the Nevada Test Site (NTS)* report (Raytheon 1994, all) explored the rationale for a potential high-speed rail corridor between Las Vegas and the Nevada Test Site to accommodate personnel.

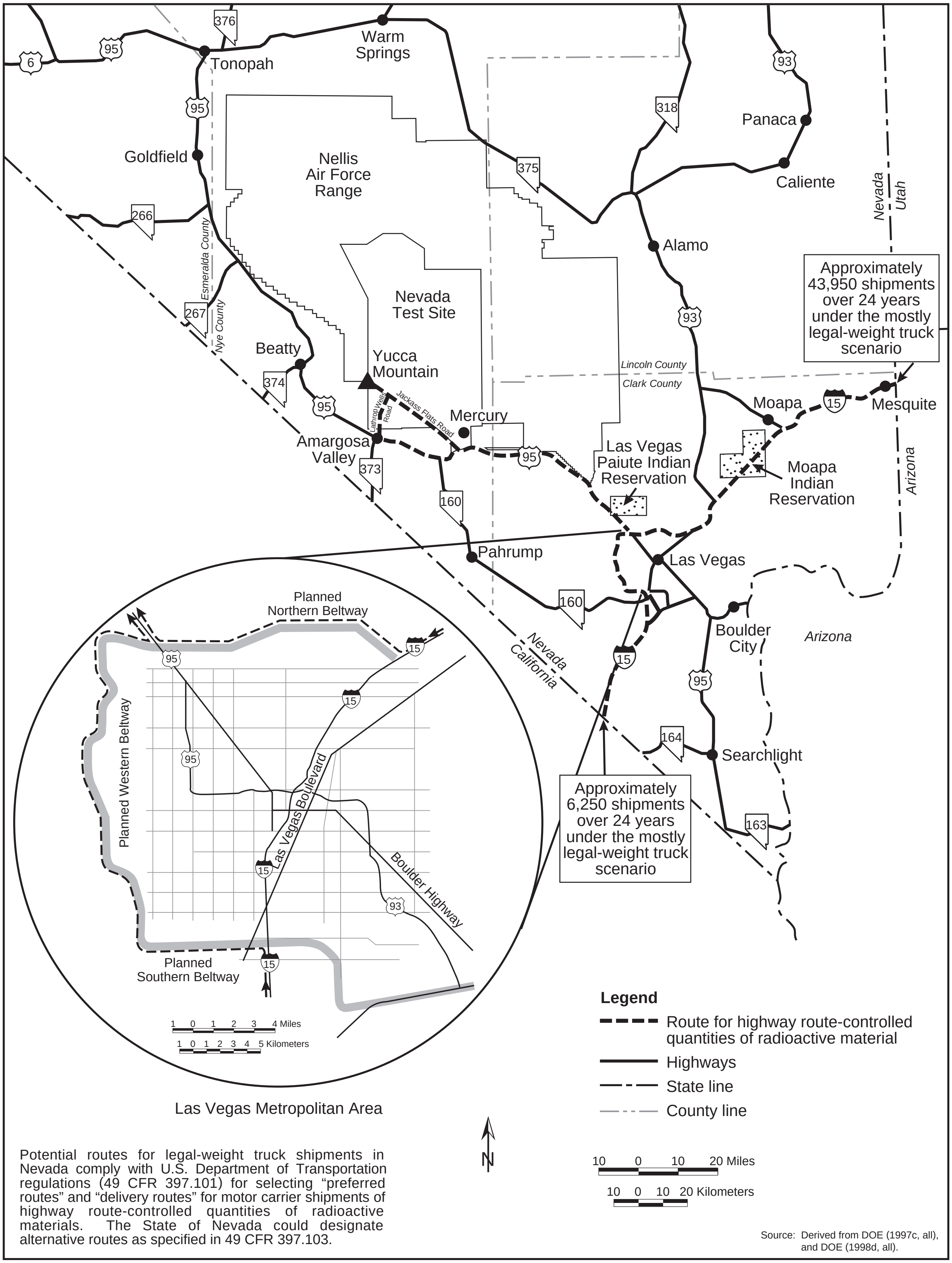


Figure J-10. Potential Nevada routes for legal-weight truck shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

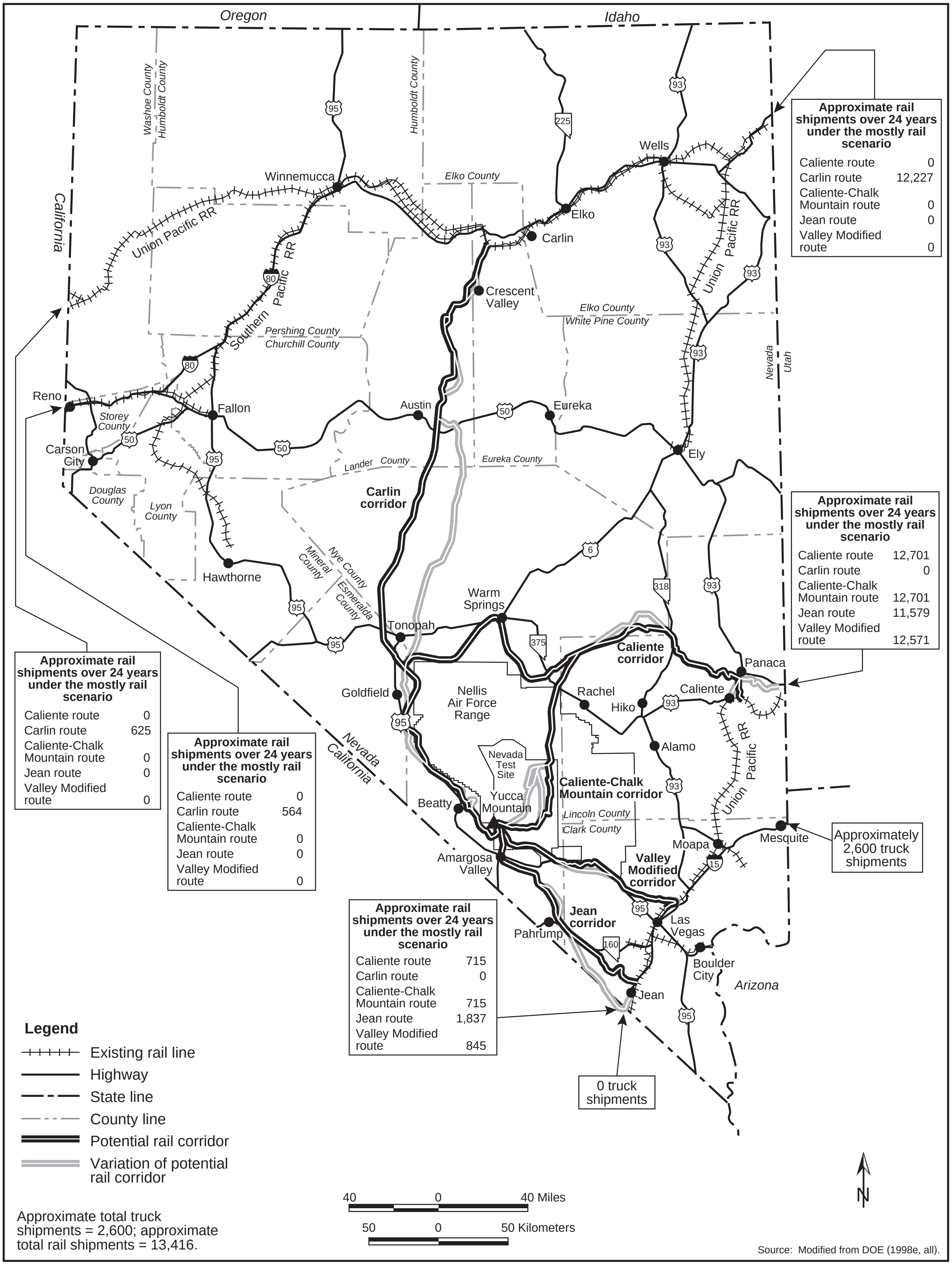


Figure J-11. Potential Nevada rail routes to Yucca Mountain and approximate number of shipments for each route.

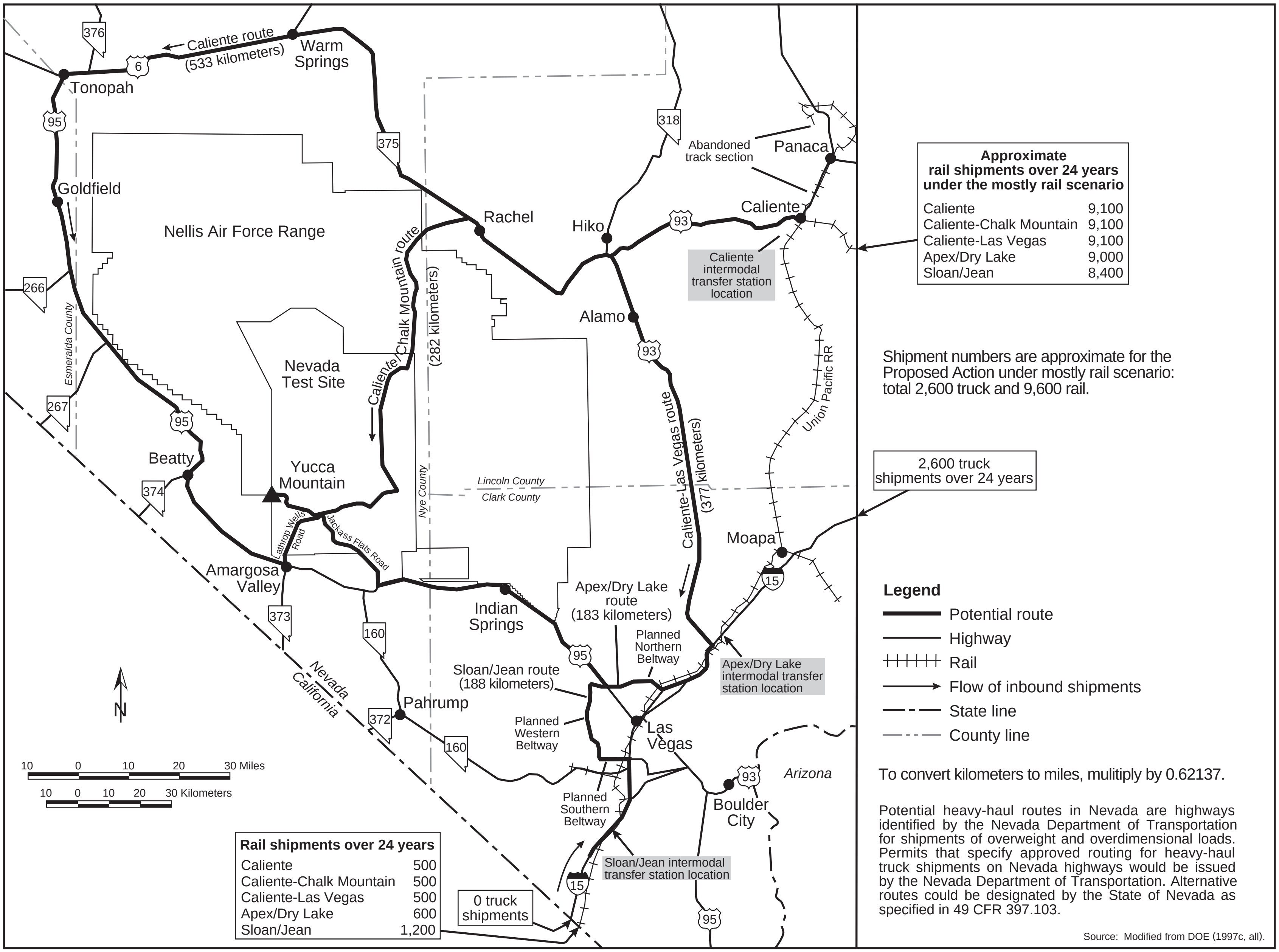


Figure J-12. Nevada routes for heavy-haul truck shipments of spent nuclear fuel and high-level radioactive waste to Yucca Mountain.

Table J-35. Route characteristics for rail and heavy-haul truck implementing alternatives.

Alternative	Rail node	Distance (kilometers)[a]			
		Rural	Suburban	Urban	Total[b]
Rail					
Caliente	Caliente	513	0	0	513
Carlin	Beowawe	520	0	0	520
Caliente-Chalk Mountain	Caliente	345	0	0	345
Jean	Jean	181	0	0	181
Valley Modified	Apex	159	0	0	159
Heavy-haul [c]					
Caliente	Caliente	533	0	0	533
Caliente-Chalk Mountain	Caliente	282	0	0	282
Caliente-Las Vegas	Caliente	356	21	0	377
Apex/Dry Lake	Apex	162	21	0	183
Sloan/Jean	Jean	145	43	0	188

a. To convert kilometers to miles, multiply by 0.62137.
b. Rounded to the nearest kilometer.
c. Heavy-haul distances are based on using the Northern, Western, and Southern Beltways in the Las Vegas area. These beltways are assumed to have suburban population density.

Table J-36. Populations in Nevada within 800 meters (0.5 mile) of routes.

Transportation scenario	Population 1990 Census
Legal-weight truck routes[a]	60,000
Rail routes Nevada border to branch rail line[b]	
Caliente	30,000
Carlin	52,000
Caliente-Chalk Mountain	30,000
Jean	30,000
Valley Modified	30,000
Branch rail lines[c]	
Caliente	2,600
Carlin	2,700
Caliente-Chalk Mountain	1,800
Jean	900
Valley Modified	800

a. Source: TRW (1999a, Table 5-1).
b. Source: TRW (1999a, Table 5-2).
c. Estimated using 3.2 persons per square kilometer – the highest value for rural populations along mainline railroads in Nevada (TRW 1999a, Table 5-2).

- The *Nevada Potential Repository Preliminary Transportation Strategy, Study 1* (TRW 1995, all), reevaluated 13 previously identified rail routes and evaluated a new route called the Valley Modified route. This study recommended four rail routes for detailed evaluation—the Caliente, Carlin, Jean, and Valley Modified routes.

- The *Nevada Potential Repository Preliminary Transportation Strategy, Study 2* (TRW 1996, all), further refined the analyses of potential rail corridor alignments presented in Study 1.

Public comments submitted to DOE during hearings on the scope of this environmental impact statement resulted in addition of a fifth potential rail corridor—Caliente-Chalk Mountain.

Table J-37. Potential road upgrades for Caliente route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance of 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to U.S. 6	Remove existing pavement, increase road base and overlay to remove frost restrictions, truck lanes where grade is greater than 4 degrees (minimum distance of 460 meters per lane), turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
U.S. 6 to U.S. 95	Same as State Route 375 to U.S. 6.
U.S. 95 to Lathrop Wells Road	Remove existing pavement on frost restricted portion, increase base and overlay to remove frost restrictions, turnout lanes every 8 kilometers (distance of 305 meters per lane), construct bypass around intersection at Beatty, bridge upgrade near Beatty.
Lathrop Wells Road to Yucca Mountain site	Asphalt overlay on existing roads.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-38. Potential road upgrades for Caliente-Chalk Mountain route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to State Route 375	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road.
State Route 375 to Rachel	Remove existing pavement, increase road base and overlay to remove frost restrictions, turnout lanes every 32 kilometers (distance of 305 meters per lane), widen road.
Rachel to Nellis Air Force Range	Pave existing gravel road.
Nellis Airforce Range Roads	Rebuild existing road.
Nevada Test Site Roads	Asphalt overlay on existing roads.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 9).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

DOE has identified 0.4-kilometer (0.25-mile)-wide corridors along each route within which it would need to obtain a right-of-way to construct a rail line and an associated access road. A corridor defines the boundaries of the route by identifying an established “zone” for the location of the railroad. For this analysis, DOE identified a single alignment for each of the corridors. These single alignments are representative of the range of alignments that DOE has considered for the corridors from engineering design and construction viewpoints. The following paragraphs describe the alignments that have been identified for the corridors. Before siting a branch rail line, DOE would conduct engineering studies in each corridor to determine a specific alignment for the roadbed, track, and right-of-way for a branch rail line.

Carlin Rail Corridor Implementing Alternative. The Carlin corridor originates at the Union Pacific main line railroad near Beowawe in north-central Nevada. The corridor is about 520 kilometers (331

Table J-39. Potential road upgrades for Caliente-Las Vegas route.[a]

Route	Upgrades
Intermodal transfer station to U.S. 93	Pave existing gravel road.
U.S. 93 to Interstate 15	Asphalt overlay on existing pavement, truck lanes where grade is greater than 4 percent (minimum distance 460 meters[b] per lane), turnout lanes every 32 kilometers[c] (distance of 305 meters per lane), widen road, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes, asphalt overlay on U.S. 95.
U.S. 95 to Mercury	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).
b. To convert meters to feet, multiply by 3.2808.
c. To convert kilometers to miles, multiply by 0.62137.

Table J-40. Potential road upgrades for Apex/Dry Lake route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Rebuild frontage road to U.S. 93. Rebuild U.S. 93/Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).

Table J-41. Potential road upgrades for Sloan/Jean route.[a]

Route	Upgrades
Intermodal transfer station to Interstate 15	Overlay and widen existing road to Interstate 15 interchange, rebuild Interstate 15 interchange.
Interstate 15 to U.S. 95	Increase existing two-lane Las Vegas Beltway to four lanes.
U.S. 95 to Mercury Exit	Asphalt overlay on U.S. 95.
Mercury Exit to Yucca Mountain site	Asphalt overlay on Jackass Flats Road, rebuild road when required.

a. Source: TRW (1999b, Heavy-Haul Truck Files, Item 4).

miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-42 lists possible variations in the alignment of this corridor.

Caliente Rail Corridor Implementing Alternative. The Caliente corridor originates at an existing siding to the Union Pacific mainline railroad near Caliente, Nevada. The Caliente and Carlin corridors converge near the northwest boundary of the Nellis Air Force Range. Past this point, they are identical. The Caliente corridor would be 513 kilometers (320 miles) long from the Union Pacific line connection to the Yucca Mountain site. Table J-43 lists possible alignment variations for this corridor.

Caliente-Chalk Mountain Rail Corridor Implementing Alternative. The Caliente-Chalk Mountain corridor is identical to the Caliente corridor until it approaches the northern boundary of the Nellis Air Force Range. At this point the Caliente-Chalk Mountain corridor turns south through the Nellis Air Force Range and the Nevada Test Site to the Yucca Mountain site. The corridor would be 345 kilometers (214 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain Site. Table J-44 lists possible alignment variations for this corridor.

Table J-42. Possible alignment variations of the Carlin corridor.[a]

Corridor	Description
Crescent Valley	Would diverge from the analyzed alignment near Cortez Mining Operation; would travel through nonagricultural lands adjacent to alkali flats but would affect larger area of private land.
Wood Spring	Would diverge from the analyzed alignment and use continuous 2-percent grade to descend from Dry Canyon Summit in Toiyabe range; would be shorter than the analyzed alignment but would have steeper grade.
Rye Patch	Would travel through Rye Patch Canyon, which has springs, riparian areas, and game habitats; would divert from the analyzed alignment, maintaining distance of 420 meters[b] from Rye Patch Spring and at least 360 meters from riparian areas throughout Rye Patch Canyon, except at crossing of riparian area near south end of canyon; would avoid game habitat (sage grouse strutting area).
Steiner Creek	Would diverge from the analyzed alignment at north end of Rye Patch Canyon. Would avoid crossing private lands, two known hawk-nesting areas, and important game habitat (sage grouse strutting area) in the analyzed alignment.
Monitor Valley	Would travel through less populated Monitor Valley (in comparison to Big Smokey Valley).
Mud Lake[c]	Would travel farther from west edge of Mud Lake, which has known important archaeological sites.
Goldfield[c]	Would avoid crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force.
Bonnie Claire[c]	Would avoid crossing Nellis Air Force Range boundary near Scotty's Junction, avoiding potential land-use conflicts with Air Force.
Oasis Valley[c]	Would enable flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected route through this area, further studies would ensure small environmental impacts.
Beatty Wash[c]	Would provide a corridor through Beatty Wash that was longer, but required less severe earthwork than the analyzed alignment.

a. Source: TRW (1999b, Rail Files, Item 6).
b. To convert meters to feet, multiply by 3.2808.
c. Common with Caliente corridor.

Table J-43. Possible alignment variations of the Caliente corridor.[a]

Corridor	Description
Caliente[b]	Would connect with Union Pacific line at existing siding in Town of Caliente.
Crestline[b]	Would connect with Union Pacific line near east end of existing siding at Crestline.
White River	Would avoid potential conflict with Weepah Spring Wilderness Study Area.
Garden Valley	Would put more distance between rail corridor and private lands in Garden Valley and Coal Valley.
Mud Lake[c]	Would travel farther from west edge of Mud Lake, which has known important archaeological sites.
Goldfield[c]	Would avoid crossing Nellis Air Force Range boundary near Goldfield, avoiding potential land-use conflicts with Air Force.
Bonnie Claire[c]	Would avoid crossing Nellis Air Force Range boundary near Scotty's Junction, avoiding potential land-use conflicts with Air Force.
Oasis Valley[c]	Would enable flexibility in crossing environmentally sensitive Oasis Valley area. If DOE selected route through this area, further studies would ensure small environmental impacts.
Beatty Wash[c]	Would provide corridor through Beatty Wash that was longer, but required less severe earthwork than the analyzed alignment.

a. Source: TRW (1999b, Rail Files, Item 6).
b. Common with Caliente-Chalk Mountain corridor.
c. Common with Carlin corridor.

Table J-44. Possible alignment variations of the Caliente-Chalk Mountain corridor.[a]

Corridor	Description
Mercury Highway	To provide flexibility in choosing path, would travel north through center of Nevada Test Site.
Tonopah	To provide flexibility in choosing path through Nevada Test Site; would travel north along western boundary of Nevada Test Site.
Mine Mountain	Would provide flexibility in minimizing impacts to local archaeological sites.
Area 4	Would provide flexibility in choosing path through Nevada Test Site.

a. Source: TRW (1999b, Rail Files, Item 8).

Jean Rail Corridor Implementing Alternative. The Jean corridor originates at the existing Union Pacific mainline railroad near Jean, Nevada. The corridor would be 181 kilometers (112 miles) long from the tie-in point at the Union Pacific line to the Yucca Mountain site. Table J-45 lists possible variations for this corridor.

Table J-45. Possible alignment variations of the Jean corridor.[a]

Corridor	Description
North Pahrump	Would minimize impacts to approximately 4 kilometers[b] of private land on northeast side of Pahrump.
Stateline Pass	Would provide option to crossing Spring Mountains at Wilson Pass; would diverge from analyzed alignment in Pahrump Valley; would parallel Nevada-California border, traveling along southwestern edge of Spring Mountains and crossing border twice.

a. Source: TRW (1999b, Rail Files, Item 6).
b. 4 kilometers = 2.5 miles (approximate).

Valley Modified Rail Corridor Implementing Alternative. The Valley Modified corridor originates at an existing rail siding off the Union Pacific mainline railroad northeast of Las Vegas. The corridor is about 159 kilometers (98 miles) long from the tie-in point with the Union Pacific line to the Yucca Mountain site. Table J-46 lists the possible variations in alignment for this corridor.

Table J-46. Possible alignment variations of the Valley Modified corridor.[a]

Corridor	Description
Indian Hills	Would avoid entrance to Nellis Air Force Range north of Town of Indian Springs by traveling south of town.
Sheep Mountain	Would increase distance from private land in Las Vegas and proposed 30-square-kilometer[b] Bureau of Land Management land exchange with city.
Valley Connection	Would locate transfer operations at Union Pacific Valley Yard rather than Dike siding. Overflights of Dike siding from Nellis Air Force Base could conflict with switching operations.

a. Source: TRW (1999b, Rail Files, Item 6).
b. 30 square kilometers = 7,410 acres (approximate).

J.3.1.3 Sensitivity of Analysis Results to Routing Assumptions

In addition to analyzing the impacts of using highway routes that would meet Department of Transportation requirements for transporting spent nuclear fuel, DOE evaluated how the estimated impacts would differ if legal-weight trucks used other routes in Nevada. Six other routes identified in a 1989 study by the Nevada Department of Transportation (Ardila-Coulson 1989, pages 36 and 45) were selected for this analysis. The Nevada Department of Transportation study described the routes as follows:

Route A. Minimum distance and minimum accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on Nevada 318, south on U.S. 93, south on I-15, west on Craig Road, north on U.S. 95

Route B. Minimum population density and minimum truck accident rate.
South on U.S. 93A, south on U.S. 93, west on U.S. 6, south on U.S. 95.

Both of these two routes use the U.S. 6 truck bypass in Ely.

Alternative route possibilities were identified between I-15 at Baker, California and I-40 at Needles, California to Mercury. These alternative routes depend upon the use of U.S. 95 in California, California 127 and the Nipton Road.

Route C. From Baker with California 127.
North on California 127, north on Nevada 373, south on U.S. 95

Route D. From Baker without California 127.
North on I-15, west on Nevada 160, south on U.S. 95

Route E. From Needles with U.S. 95, California 127, and the Nipton Road.
North on U.S. 95, west on Nevada 164, west on I-15, north on California 127, north on Nevada 373, south on U.S. 95

Route F. From Needles without California 127 and the Nipton Road.
West on I-40, east on I-15, west on Nevada 160, south on U.S. 95

Table J-47 identifies the sensitivity cases evaluated based on the Nevada Department of Transportation routes. Table J-48 lists the range of impacts in Nevada of using these different routes for the mostly legal-weight truck analysis scenario. The tables compare the impacts estimated for the highways identified in the Nevada study to those estimated for shipments that would follow routes allowed by current Department of Transportation regulations for Highway Route-Controlled Quantities of Radioactive Materials. Because the State of Nevada has not designated alternative or additional preferred routes for use by these shipments, as permitted under Department of Transportation regulations (49 CFR 397.103), DOE has assumed that shipments of spent nuclear fuel and high-level radioactive waste would

Table J-47. Nevada routing sensitivity cases analyzed for a legal-weight truck.

Case	Description
Case 1	To Yucca Mountain via Barstow, California, using I-15 to Nevada 160 to Nevada 160 (Nevada D and F)
Case 2	To Yucca Mountain via Barstow using I-15 to California route 127 to Nevada 373 to US 95 (Nevada C)
Case 3	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to California 127 to Nevada 373 and U.S. 95 (Nevada E)
Case 4	To Yucca Mountain via Needles using U.S. 95 to Nevada 164 to I-15 to Nevada 160 (variation of Nevada E)
Case 5	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to US 6 to U.S. 95 (Nevada B)
Case 6	To Yucca Mountain via Wendover using U.S. 93 Alternate to U.S. 93 to Nevada 318 to U.S. 93 to I-15 to the Las Vegas Beltway to U.S. 95 (Nevada A)

Table J-48. Comparison of impacts from the sensitivity analyses (national and Nevada).

	Base case		Barstow via Nevada 160		Barstow via U.S. 95		Needles via Nevada 160		Needles via U.S. 95		Wendover via U.S. 95		Wendover via Las Vegas Beltway	
	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada	National	Nevada
Public incident-free dose (person-rem)	35,000	2,700	39,000	2,500	38,000	710	39,000	2,900	37,000	1,100	38,000	7,100	38,000	7,600
Occupational incident-free dose (person-rem)	11,000	1,600	12,000	1,500	12,000	1,100	12,000	1,600	12,000	1,200	12,000	2,600	12,000	2,700
Pollution health effects nonradioactive	0.60	0.006	0.68	0.005	0.68	0.004	0.64	0.003	0.64	0.001	0.61	0.011	0.61	0.011
Public incident-free risk of latent cancer fatality	17	1.4	19	1.2	19	0.4	18	1.4	19	0.6	19	3.5	19	3.8
Occupational incident-free risk of latent cancer fatality	4.5	0.6	4.9	0.6	4.8	0.4	4.7	0.6	4.7	0.5	4.7	1.0	4.8	1.1
Radiological accident risk (person-rem)	130	0.5	100	0.4	100	0.0	98	0.4	98	0.1	140	1.0	140	1.0
Radiological accident risk of latent cancer fatality	0.067	0.00024	0.0	0.00020	0.050	0.00001	0.049	0.00021	0.049	0.00003	0.069	0.0005	0.069	0.0005
Traffic fatalities	3.9	0.5	4.3	0.4	4.0	0.1	4.2	0.5	4.0	0.2	4.7	1.2	4.8	1.3

enter Nevada on I-15 from either the northeast or southwest. The analysis assumed that shipments traveling on I-15 from the northeast would use the northern Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site. Shipments from the southwest on I-15 would use the southern and western Las Vegas Beltway to connect to U.S. 95 and continue to the Nevada Test Site.

J.3.2 ANALYSIS OF INCIDENT-FREE TRANSPORTATION IN NEVADA

The analysis of incident-free impacts to populations in Nevada addressed transportation through urban, suburban, and rural population zones. The population densities that were assumed for the analysis were determined using the HIGHWAY and INTERLINE computer programs. The population in the 800-meter (0.5-mile) region of influence used to evaluate the impacts of incident-free transportation for both legal-weight truck and rail shipments is listed in Table J-36.

Results for incident-free transportation of spent nuclear fuel and high-level radioactive waste for Inventory Modules 1 and 2 are presented in Section J.3.4.

J.3.3 ANALYSIS OF TRANSPORTATION ACCIDENT SCENARIOS IN NEVADA

Section J.1.4 discusses the methodology for estimating the risks of accidents that could occur during rail and truck transportation of spent nuclear fuel and high-level radioactive waste. Section J.3.5 describes the results of the accident risk analysis for Inventory Modules 1 and 2.

J.3.3.1 Intermodal Transfer Station Accident Methodology

Shipping casks would arrive at an intermodal transfer station in Nevada by rail, and a gantry crane would transfer them from the railcars to heavy-haul trucks for transportation to the repository. The casks, which would not be opened or altered in any way at the intermodal transfer station, would be certified by the Nuclear Regulatory Commission and would be designed for accident conditions specified in 10 CFR Part 71. Impact limiters, which would protect casks against collisions during transportation, would remain in place during transfer operations at the intermodal transfer station.

DOE performed an accident screening process to identify credible accidents that could occur at an intermodal transfer station with the potential for compromising the integrity of the casks and releasing radioactive material. The external events listed in Table J-49 were considered, along with an evaluation of their potential applicability.

As indicated from Table J-49, the only accident-initiating event identified from among the feasible external events was the aircraft crash. Such events would be credible only for casks being handled or on transport vehicles at an intermodal transfer station in the Las Vegas area (Apex/Dry Lake or Sloan/Jean). For a station in the Las Vegas area, an aircraft crash would be from either commercial aircraft operations at McCarran airport or military operations from Nellis Air Force Base.

Among the internal events, the only potential accident identified was a drop of the cask during transfer operations. This accident would bound the other events considered, including drops from the railcar or truck (less fall height would be involved than during the transfer operations). Collisions, derailments, and other accidents involving the transport vehicles at the intermodal transfer would not damage the casks due to the requirement that they be able to withstand high-speed impacts and the low velocities of the transport vehicles at the intermodal transfer station.

Sabotage events were also considered as potential accident-initiating events at an intermodal transfer station. Section J.1.5 evaluates such events.

Table J-49. Screening analysis of external events considered potential accident initiators at intermodal transfer station.

Event	Applicability
Aircraft crash	Retained for further evaluation
Avalanche	(a)
Coastal erosion	(a)
Dam failure	See flooding
Debris avalanching	(a)
Dissolution	(b)
Epeirogenic displacement (tilting of the earth's crust)	(c)
Erosion	(b)
Extreme wind	(c)
Extreme weather	(e)
Fire (range)	(b)
Flooding	(d)
Denudation	(b)
Fungus, bacteria, algae	(b)
Glacial erosion	(b)
High lake level	(b)
High tide	(a)
High river stage	See flooding
Hurricane	(a)
Inadvertent future intrusion	(b)
Industrial activity	Bounded by aircraft crash
Intentional future intrusion	(b)
Lightning	(c)
Loss of off/on site power	(c)
Low lake level	(b)
Meteorite impact	(e)
Military activity	Retained for further evaluation
Orogenic diastrophism	(e)
Pipeline accident	(b)
Rainstorm	See flooding
Sandstorm	(c)
Sedimentation	(b)
Seiche	(a)
Seismic activity, uplifting	(c)
Seismic activity, earthquake	(c)
Seismic activity, surface fault	(c)
Seismic activity, subsurface fault	(c)
Static fracturing	(b)
Stream erosion	(b)
Subsidence	(c)
Tornado	(c)
Tsunami	(a)
Undetected past intrusions	(b)
Undetected geologic features	(b)
Undetected geologic processes	(c)
Volcanic eruption	(e)
Volcanism, magmatic activity	(e)
Volcanism, ash flow	(c)
Volcanism, ash fall	(b)
Waves (aquatic)	(a)

a. Conditions at proposed sites do not allow event.
b. Not a potential accident initiator.
c. Bounded by cask drop accident considered in the internal events analysis.
d. Shipping cask designed for event.
e. Not credible, see evaluation for repository.

Accident Analysis

1. *Cask Drop Accident.* The only internal event retained after the screening process was a failure of the gantry crane (due to mechanical failure or human error) during the transfer of a shipping cask from a railcar to a heavy-haul truck. The maximum height between the shipping cask and the ground during the transfer operation would be less than 6 meters (19 feet) (TRW 1999a, Heavy-Haul Files, Item 11). The casks would be designed to withstand a 9-meter (30-foot) drop. Therefore, the cask would be unlikely to fail during the event, especially because the impact energy from the 6-meter drop would be only 65 percent of the minimum design requirement.

2. *Aircraft Crash Accident.* Two of the three intermodal transfer station locations are near airports that handle large volumes of air traffic. The Apex/Dry Lake location is about 16 kilometers (10 miles) northeast of the Nellis Air Force Base runways. Between 60,000 and 67,000 takeoffs and landings occur at Nellis Air Force Base each year (Luedke 1997, all). The Sloan/Jean intermodal transfer area begins about 16 kilometers southwest of McCarran International Airport in Las Vegas. In 1996, McCarran had an average of 1,300 daily aircraft operations (Best 1998, all). Because of the large number of aircraft operations at these airports, the probability of an aircraft crash on the proposed intermodal transfer station could be within the credible range. To assess the consequences of an aircraft crash, an analysis evaluated the ability of large aircraft projectiles [jet engines and jet engine shafts (DOE 1996b, page 58)] to penetrate the shipping casks. The analysis used a recommended formula (DOE 1996b, page 69) for predicting the penetration of steel targets, as follows:

$$T^{1.5} = 0.5 \times M \times V^2 \div 17{,}400 \times K_s \times D^{1.5}$$

where:

T = predicted thickness to just perforate a steel plate (inches)
M = projectile mass (weight/gravitational acceleration)
V = projectile impact velocity (feet per second)
K_s = constant depending on the grade of steel (usually about 1.0)
D = projectile diameter (inches)

The projectile characteristics listed in Table J-50 are from Davis, Strenge, and Mishima (1998, all). The velocity used is about 130 meters (427 feet) per second, which is representative of aircraft velocities near airports (maximum velocity during takeoff and landing operations). A higher velocity [about 180 meters (590 feet) per second] was assumed for the projectile found to be limiting in terms of ability to penetrate (commercial engine shaft) to provide perspective on the influence of velocity on the penetration thickness. Table J-51 lists the results of the penetration calculation.

Table J-50. Projectile characteristics.[a]

Aircraft	Engine weight (kilograms)[b]	Engine diameter (centimeters)[c]
Small military	420	71
Commercial	3,900	270

a. Source: Davis, Strenge, and Mishima (1998, Table 1).
b. To convert kilograms to pounds, multiply by 2.2046.
c. To convert centimeters to inches, multiply by 0.3937.

The results indicate that none of the aircraft projectiles considered would penetrate the shipping casks, which would have metal shield walls about 18 centimeters (7 inches) thick (JAI 1996, all).

This evaluation found no credible accidents with the potential for radioactive release at an intermodal transfer station.

Table J-51. Results of aircraft projectile penetration analysis.[a]

Projectile	Velocity (meters per second)[b]	Penetration thickness (centimeters)[c,d]
Small military engine	130	2.5
Small military shaft	130	2.5
Commercial engine	130	3.0
Commercial shaft	130	3.7
Commercial shaft	180	5.9

a. Source: Davis, Strenge, and Mishima (1998, Table 2).
b. To convert meters to feet, multiply by 3.2808.
c. To convert centimeters to inches, multiply by 0.3937.
d. Penetration through steel plate.

J.3.4 IMPACTS IN NEVADA FROM INCIDENT-FREE TRANSPORTATION FOR INVENTORY MODULES 1 AND 2

This section presents the analysis of impacts to occupational and public health and safety in Nevada from incident-free transportation of spent nuclear fuel and high-level radioactive waste in Inventory Modules 1 and 2. The analysis assumed that the routes, population densities, and shipment characteristics (for example, radiation from shipping casks) for shipments under the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference was the projected number of shipments that would travel to the repository.

The following sections provide detailed information on the range of potential impacts to occupational and public safety and health from incident-free transportation of Modules 1 and 2 that result from legal-weight trucks and the 10 alternative transportation routes considered in Nevada. National impacts of incident-free transportation of Modules 1 and 2 incorporating Nevada impacts are discussed together with other cumulative impacts in Chapter 8.

J.3.4.1 Mostly Legal-Weight Truck Scenario

Tables J-52 and J-53 list estimated incident-free impacts in Nevada for the mostly legal-weight truck scenario for shipments of materials included in Inventory Modules 1 and 2.

J.3.4.2 Nevada Rail Implementing Alternatives

Table J-54 lists the range of estimated incident-free impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations for a branch line in each of the five possible rail corridors DOE is evaluating. These include the impacts of about 2,600 legal-weight truck shipments from commercial sites that could not use rail casks to ship spent nuclear fuel.

J.3.4.3 Nevada Heavy-Haul Truck Implementing Alternatives

Radiological Impacts

Intermodal Transfer Station Impacts. Involved worker exposures (the analysis assumed that the noninvolved workers would receive no radiation exposure and thus required no further analysis) would occur during both inbound (to the repository) and outbound (to the 77 sites) portions of the shipment campaign. DOE used the same involved worker level of effort it used in the analysis of intermodal transfer station worker industrial safety impacts to estimate collective involved worker radiological impacts (that is, 16 full-time equivalents per year). The collective worker radiation doses were adapted from a study (Smith, Daling and Faletti 1992, all) of a spent nuclear fuel transportation system, which

Table J-52. Population doses and radiological impacts from incident-free Nevada transportation for mostly legal-weight truck scenario – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1			
Involved worker			
Collective dose (person-rem)	2,900	30	2,900
Estimated latent cancer fatalities	1.2	0.01	1.2
Public			
Collective dose (person-rem)	5,100	26	5,100
Estimated latent cancer fatalities	2.5	0.01	2.5
Module 2			
Involved worker			
Collective dose (person-rem)	3,000	40	3,000
Estimated latent cancer fatalities	1.2	0.02	1.2
Public			
Collective dose (person-rem)	5,300	30	5,300
Estimated latent cancer fatalities	2.6	0.02	2.6

a. Impacts are totals for shipments over 38 years.
b. Includes impacts at intermodal transfer stations.
c. Totals might differ from sums due to rounding.

Table J-53. Population health impacts from vehicle emissions during incident-free Nevada transportation for the mostly legal-weight truck scenario – Modules 1 and 2.[a]

Vehicle emission-related fatalities	Legal-weight truck shipments	Rail shipments of naval spent nuclear fuel[b]	Total[c]
Module 1	0.01	0.0004	0.01
Module 2	0.01	0.0005	0.01

a. Impacts are totals for shipments over 38 years.
b. Includes heavy-haul truck shipments in Nevada.
c. Totals might differ from sums due to rounding.

Table J-54. Radiological and nonradiological impacts from incident-free Nevada transportation for the mostly rail scenario – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail shipments	Total[b]
Module 1			
Involved worker			
Collective dose (person-rem)	370	280 - 460	650 - 830
Estimated latent cancer fatalities	0.15	0.11 - 0.18	0.26 - 0.33
Public			
Collective dose (person-rem)	430	190 - 270	620 -700
Estimated latent cancer fatalities	0.22	0.09 - 0.14	0.31 - 0.36
Estimated vehicle emission-related fatalities	0.00019	0.004	0.0042

a. Impacts are totals for 38 years (2010 to 2048).
b. Totals might differ from sums due to rounding.

was also performed for the commercial sites. That study found that the collective worker doses that could be incurred during similar inbound and outbound transfer operations of a single loaded (with commercial spent nuclear fuel) and unloaded cask were approximately 0.027 and 0.001 person-rem per cask, respectively, as listed in Table J-55.

The analysis used these inbound and outbound collective dose factors to calculate the involved worker impacts listed in Table J-56 for Module 1 and Module 2 inventories in the same manner it used for

Table J-55. Collective worker doses (person-rem) from transportation of a single cask.[a,b]

Inbound	Inbound CD[b]	Outbound	Outbound CD
Receive transport vehicle and loaded cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	6.3×10^{-3}	Receive transport vehicle and empty cask. Monitor, inspect, unhook offsite drive unit, and attach onsite drive unit.	0.0
Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	1.4×10^{-3}	Move cask to parking area and wait for wash down station. Attach to carrier puller when ready.	5.4×10^{-4}
Move cask to receiving and handling area.	9.2×10^{-5}	Move cask to receiving and handling area.	8.0×10^{-5}
Remove cask from carrier and place on cask cart.	4.3×10^{-3}	Remove cask from carrier and place on cask cart.	2.2×10^{-4}
Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	7.0×10^{-4}	Connect onsite drive unit and move cask to inspection area; disconnect onsite drive unit.	3.3×10^{-5}
Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	1.4×10^{-2}	Hook up offsite drive unit, move to gatehouse, perform final monitoring and inspection of cask.	8.3×10^{-5}
Notify appropriate organizations of the shipment's departure.	0.0	Notify appropriate organizations of the shipment's departure.	0.0
Total	$\mathbf{2.7\times10^{-5}}$	**Total**	$\mathbf{8.8\times10^{-5}}$

a. Adapted from Smith, Daling and Faletti (1992, Table 4.2).
b. Values are rounded to two significant figures; therefore, totals might differ from sums of values.
c. CD = collective dose (person-millirem per cask).

Table J-56. Doses and radiological health impacts to involved workers from intermodal transfer station operations – Modules 1 and 2.[a,b]

	Module 1		Module 2	
Group	Dose	Latent cancer fatality	Dose	Latent cancer fatality
Maximally exposed individual worker[c]	12	0.005	12	0.005
Involved worker population[d]	530	0.21	550	0.22

a. Includes estimated impacts from handling 300 shipments of U.S. Navy fuel that would be shipped by rail under the mostly legal-weight truck transportation scenario. DOE estimated the impacts from these shipments by adjusting the impacts from the approximately 19,300 shipments (9,650 × 2) that would pass through the intermodal transfer station under the mostly rail scenario.
b. Totals for 24 years of operations.
c. The estimated probability of a latent cancer fatality in an exposed individual.
d. The estimated number of latent cancer fatalities in an exposed involved worker population.

commercial power reactor spent nuclear fuel impacts. The number of inbound and outbound shipments for Module 1 and Module 2 inventories is from Section J.1.2. The worker impacts reflect two-way operations.

Incident-Free Transportation. Table J-57 lists the range of estimated incident-free impacts in Nevada for the use of heavy-haul trucks to ship the materials included in Inventory Modules 1 and 2. It lists impacts that would result from operations on each of the five possible highway routes in Nevada DOE is evaluating. These include impacts of about 2,600 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel using rail casks.

Table J-57. Radiological and nonradiological health impacts from incident-free transportation for the heavy-haul truck implementing alternatives – Modules 1 and 2.[a]

Category	Legal-weight truck shipments	Rail and heavy-haul truck shipments[b]	Total[c]
Involved worker			
Collective dose (person-rem)	370	830 - 1,000	1,200 - 1,400
Estimated latent cancer fatalities	0.15	0.33 - 0.40	0.48 - 0.55
Public			
Collective dose (person-rem)	430	1,200 - 3,200	1,600 - 3,700
Estimated latent cancer fatalities	0.22	0.60 - 1.6	0.82 -1.8
Estimated vehicle emission-related fatalities	0.00019	0.03	0.05

a. Impacts are totals for 38 years (2010 to 2048).
b. Includes impacts to workers at an intermodal transfer station.
c. Totals might differ from sums due to rounding.

J.3.5 IMPACTS IN NEVADA FROM TRANSPORTATION ACCIDENTS FOR INVENTORY MODULES 1 AND 2

The analysis assumed that the routes, population densities, and shipment characteristics (for example, assumed radioactive material contents of shipping casks) for the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of shipments that would travel to the repository. As listed in Table J-1, Module 2 would include about 3 percent more shipments than Module 1.

J.3.5.1 Mostly Legal-Weight Truck Scenario

Radiological Impacts

The analysis estimated the radiological impacts of accidents in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. The radiological health impacts associated with Module 1 would be 0.86 person-rem and for Module 2 would be 0.88 person-rem (see Table J-58). These impacts would occur over 34 years in a population of more than 1 million people who lived within 80 kilometers (50 miles) of the Nevada routes that DOE would use. This dose risk would lead to about 1 chance in 1,000 of an additional cancer fatality in the exposed population. For comparison, about 220,000 in a population of 1 million people would suffer fatal cancers from other causes (ACS 1998, page 10).

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste by legal-weight trucks in Nevada for the mostly legal-weight truck scenario for shipments of the materials included in Inventory Modules 1 and 2. It estimated that there would be 0.9 fatality over 34 years for Module 1 and 0.93 fatality for Module 2 (see Table J-58). The estimate of traffic fatalities includes the risk of fatalities from 300 shipments of naval spent nuclear fuel.

J.3.5.2 Nevada Rail Implementing Alternatives

Industrial Safety Impacts

Table J-59 lists the estimated industrial safety impacts in Nevada for the operation of a branch rail line to ship the materials included in Inventory Modules 1 and 2. The table lists impacts that would result from operations for a branch line in each of the five possible rail corridors in Nevada that DOE is evaluating.

The representative workplace loss incidence rate for each impact parameter (as compiled by the Bureau of Labor Statistics) was used as a multiplier to convert the operations crew level of effort to expected

Table J-58. Accident radiological health impacts for Modules 1 and 2 – Nevada transportation.[a]

Transportation scenario	Dose risk (person-rem)	Latent cancer fatalities	Traffic fatalities
Legal-weight truck	0.88[b]	0.0004	0.9
Legal-weight truck for the mostly rail scenario	0.1	0.00006	0.1
Mostly rail (Nevada rail implementing alternatives)			
Caliente	0.02	8.7×10^{-6}	0.13
Carlin	0.03	1.6×10^{-5}	0.17
Sloan/Jean	0.11	5.3×10^{-5}	0.10
Apex/Dry Lake	0.01	7.0×10^{-6}	0.08
Caliente-Chalk Mountain	0.01	6.9×10^{-6}	0.09
Mostly rail (Nevada heavy-haul implementing alternatives)			
Caliente	0.34	1.7×10^{-4}	1.2
Caliente-Chalk Mountain	0.28	1.4×10^{-4}	0.65
Caliente-Las Vegas	1.02	5.1×10^{-4}	0.90
Apex/Dry Lake	0.94	4.7×10^{-4}	0.46
Jean	6.5	3.2×10^{-3}	0.49

a. Impacts over 38 years.
b. Estimates of dose risk are for the transportation of the materials included in Module 2. Estimates of dose risk for transportation of the materials in Module 1 would be slightly (about 3 percent) lower.

Table J-59. Rail corridor operation worker physical trauma impacts (Modules 1 and 2).

Worker group and impact category	Corridor				
	Caliente	Carlin	Chalk Mountain	Jean	Valley Modified
Involved workers					
TRC[a]	200	200	200	150	150
LWC[b]	110	110	110	82	82
Fatalities	0.4	0.4	0.4	0.3	0.3
Noninvolved workers[c]					
TRC	9	9	9	7	7
LWC	5	5	5	3	3
Fatalities	0.01	0.01	0.01	0.01	0.01
All workers (totals)[d]					
TRC	210	210	210	160	160
LWC	120	120	120	85	85
Fatalities	0.4	0.4	0.4	0.3	0.3
Traffic fatalities[e]	1.1	1.1	1.1	0.8	0.8

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

industrial safety losses. The involved worker full-time equivalent multiples that DOE would assign to operate each rail corridor each year was estimated to be 36 to 47 full-time equivalents, depending on the corridor for the period of operations (scaled from cost data in TRW 1996, Appendix E). Noninvolved worker full-time equivalent multiples were unavailable, so DOE assumed that the noninvolved worker level of effort would be similar to that for the repository operations work force—about 25 percent of that for involved workers. The Bureau of Labor Statistics loss incidence rate for each total recordable case, lost workday, and fatality trauma category (for example, the number of total recordable cases per full-time equivalent) was multiplied by the involved and noninvolved worker full-time equivalent multiples to project the associated trauma incidence.

The involved worker total recordable case incidence rate, 170,000 total recordable cases in a workforce of 1,620,000 workers (0.11 total recordable case per full-time equivalent) reflects losses in the Trucking and Warehousing sector during 1996. The same Bureau of Labor Statistics period of record and industry sector was used to select the involved worker lost workday case incidence rate [96,000 lost workday cases in a workforce of 1,620,000 workers (0.06 lost workday case per full-time equivalent)]. The involved worker fatality incidence rate, 22 fatalities in a workforce of 100,000 workers (0.0002 fatality per full-time equivalent) reflects losses in the Transportation and Material Moving Occupations sector during the Bureau of Labor Statistics 1994-to-1995 period of record.

The noninvolved worker incidence rate of 53,000 total recordable cases in a workforce of 2,870,000 workers (0.02 total recordable case per full-time equivalent) reflects losses in the Engineering and Management Services sector during the Bureau of Labor Statistics 1996 period of record. DOE used the same period of record and industry sector to select the noninvolved worker lost workday case incidence rate [22,000 lost workday cases in a workforce of 2,870,000 workers (0.01 lost workday case per full-time equivalent)]. The noninvolved worker fatality incidence rate, 1.5 fatalities in a workforce of 100,000 workers (0.00002 fatality per full-time equivalent) reflects losses in the Managerial and Professional Specialties sector during the 1994-to-1995 period of record.

Table J-59 lists the results of these industrial safety calculations for the five candidate corridors under Inventory Modules 1 and 2. The table also lists estimates of the number of traffic fatalities that would occur in the course of commuting by workers to and from their construction and operations jobs. These estimates used national statistics for average commute distances [18.5 kilometers (11.5 miles) one-way (ORNL 1999, all)] and fatality rates for automobile traffic [1 per 100 million kilometers (1.5 per 100 million miles) (BTS 1998, all)].

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accident scenarios in Nevada for the Nevada rail implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-58 lists the radiological dose-risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 2,600 legal-weight truck shipments from commercial sites that could not ship spent nuclear fuel in rail casks. The risks would occur over 34 years.

Traffic Fatalities

Traffic fatalities from accidents involving transport of spent nuclear fuel and high-level radioactive waste by rail in Nevada were estimated for the Nevada rail implementing alternatives for shipments of materials included in Inventory Modules 1 and 2. Table J-58 lists the estimated number of fatalities that would occur over 34 years for a branch rail line along each of the five possible rail corridors. These estimates include the risk of fatalities from about 2,600 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks.

J.3.5.3 Nevada Heavy-Haul Truck Implementing Alternatives

Industrial Safety Impacts

Tables J-60 and J-61 list the estimated industrial safety impacts in Nevada for operations of heavy-haul trucks (principally highway maintenance safety impacts) and operation of an intermodal transfer station that would transfer loaded and unloaded rail casks between rail cars and heavy-haul trucks for shipments of the materials included in Inventory Modules 1 and 2. Table J-60 lists the estimated industrial safety impacts in Nevada for the operation of a heavy-haul route to the Yucca Mountain site. Table J-61 lists impacts that would result from the operation of an intermodal transfer station for any of the five possible routes DOE is evaluating that heavy-haul trucks could use in Nevada.

Table J-60. Industrial health impacts from heavy-haul truck route operations (Modules 1 and 2).

Worker group and impact category	Corridor: Caliente	Caliente-Chalk Mountain	Caliente-Las Vegas	Sloan/Jean	Apex/Dry Lake
Involved workers					
TRC[a]	460	460	420	250	250
LWC[b]	250	250	230	140	140
Fatalities	0.8	0.8	0.8	0.5	0.5
Noninvolved workers[c]					
TRC	21	21	19	11	11
LWC	11	11	10	6	6
Fatalities	0.02	0.02	0.02	0.01	0.01
All workers (totals)[d]					
TRC	480	480	440	260	260
LWC	260	260	240	150	150
Fatalities	0.82	0.82	0.82	0.5	0.5
Traffic fatalities[e]	2.0	2.0	1.9	1.3	1.3

a. TRC = total recordable cases (injury and illness).
b. LWC = lost workday cases.
c. Noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
d. Totals might differ from sums due to rounding.
e. Fatalities from accidents during commutes to and from jobs for involved and noninvolved workers.

Table J-61. Annual physical trauma impacts to workers from intermodal transfer station operations (Module 1 or 2).

Involved workers			Noninvolved workers[a]			All workers		
TRC[b]	LWC[c]	Fatalities	TRC	LWC	Fatalities	TRC	LWC	Fatalities
112	60	0.2	5	2	0.0	116	62	0.2

a. The noninvolved worker impacts are based on 25 percent of the involved worker level of effort.
b. TRC = total recordable cases of injury and illness.
c. LWC = lost workday cases.

Radiological Impacts of Accidents

The analysis estimated the radiological impacts of accidents in Nevada for the Nevada heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2.

Table J-58 lists the radiological dose-risk and associated risk of latent cancer fatalities. The risks include accident risks in Nevada from approximately 2,600 legal-weight truck shipments from commercial generating sites that could not ship spent nuclear fuel in rail casks. The risk would occur over 34 years.

Traffic Fatalities

The analysis estimated traffic fatalities from accidents involving the transport of spent nuclear fuel and high-level radioactive waste (including the rail portion of transportation to and from an intermodal transfer station) in Nevada for the heavy-haul truck implementing alternatives for shipments of the materials included in Inventory Modules 1 and 2. Table J-58 lists the estimated number of fatalities that would occur over 34 years for a branch rail line and for each of the five possible routes for heavy-haul trucks. The estimate for traffic fatalities includes the risk of fatalities from about 2,600 legal-weight truck shipments from commercial generators that could not ship spent nuclear fuel in rail casks.

J.3.6 IMPACTS FROM TRANSPORTATION OF OTHER MATERIALS

Other types of transportation activities associated with the Proposed Action would involve shipments of materials other than the spent nuclear fuel and high-level radioactive waste discussed in previous sections. These activities would include the transportation of people. This section evaluates occupational and public health and safety and air quality impacts from the shipment of:

- Construction materials, consumables, and personnel for repository construction and operation, including disposal containers
- Waste including low-level waste, construction and demolition debris, sanitary and industrial solid waste, and hazardous waste
- Office and laboratory supplies, mail, and laboratory samples

The analysis includes potential impacts of transporting these materials for the case in which DOE would not build a rail line to the proposed repository, because the larger number of truck shipments would lead to higher impacts than those for rail shipments, as discussed above. In addition, because the construction schedule for a new rail line would coincide with the schedule for the construction of repository facilities, trucks would deliver materials for repository construction.

Rail service would benefit the delivery of 10,000 disposal containers from manufacturers. Two 33,000-kilogram (about 75,000-pound) disposal containers and their 700-kilogram (about 1,500-pound) lids (TRW 1999b, Request #027) would be delivered on a railcar—a total of 5,000 railcar deliveries over the 24-year period of the Proposed Action. These containers would be delivered to the repository along with shipments of spent nuclear fuel and high-level radioactive waste or separately on supply trains along with shipments of materials and equipment.

If rail service was not available, disposal container components that would weigh as much as 34 metric tons (37.5 tons) would be transported to Nevada by rail and transferred to overweight trucks for shipment to the repository site. In this event, 10,000 overweight truck shipments would move the containers from a railhead to the site. The State of Nevada routinely provides permits to motor carriers for overweight, overdimension loads if the gross vehicle weight does not exceed 58.5 metric tons (64.5 tons) (TRW 1999b, Request #046).

J.3.6.1 Transportation of Personnel and Materials to Repository

The following paragraphs describe impacts that would result from the transportation of construction materials, consumables, disposal containers, supplies, mail, laboratory samples, and personnel to the repository site during the construction, operation and monitoring, and closure phases.

Human Health and Safety

Most construction materials, construction equipment, and consumables would be transported to the Yucca Mountain site on legal-weight trucks. Heavy and overdimensional construction equipment would be delivered by trucks under permits issued by the Nevada Department of Transportation. DOE estimates that about 42,000 truck shipments over 5 years would be necessary to transport materials, supplies, and equipment to the site during the construction phase.

In addition to construction materials, supplies, equipment, and disposal containers, trucks would deliver consumables to the repository site. These would include diesel fuel, cement, and other materials that would be consumed in daily operations. About 13,000 semitrailer truck shipments would occur during each year of operation. Similarly, there would be an estimated 1,000 semitrailer truck shipments during each year of monitoring and 1,200 each year during closure operations.

Over the 24-year period of the Proposed Action, the repository would receive about 300,000 truck shipments of supplies, materials, equipment, disposal containers, and consumables, including cement and other materials used in underground excavation. Most of these shipments would originate in the Las Vegas metropolitan area. In addition, an estimated 54,000 shipments of office and laboratory supplies and equipment, mail, and laboratory samples would occur during the 24 years of operation. A total of about 21 million vehicle kilometers (13 million vehicle miles) of travel would be involved. Impacts would include vehicle emissions, consumption of petroleum resources, increased truck traffic on regional highways, and fatalities from accidents. Similarly, there would be about 76,000 shipments during the 76-year monitoring period after emplacement operations and 15,000 shipments during closure activities. The number of shipments during shorter or longer monitoring periods would be proportionately fewer or larger. Table J-62 summarizes these impacts.

Table J-62. Human health and safety impacts from shipments of material to the repository.[a]

Phase	Kilometers[b] traveled (millions)	Traffic fatalities	Fuel consumption (thousands of liters)[c]	Vehicle emissions-related fatalities
Construction	8.2 - 9.9	0.14 - 0.17	1,900 - 2,300	0.0006 - 0.0007
Operation and monitoring				
Emplacement and development	29 - 66	0.5 - 1.1	7,000 - 15,000	0.002 - 0.005
Monitoring				
26 years	6.5	0.1	1,500	0.0005
76 years	19	0.3	4,500	0.0014
276 years	69	1.2	16,000	0.005
Closure	4.1	0.1	1,000	0.0003

a. Impacts are totals for 24 years of operations.
b. To convert kilometers to miles, multiply by 0.62137.
c. To convert liters to gallons, multiply by 0.26418.

During the construction phase, many employees would use their personal automobiles to travel to construction areas on the repository site and to highway or rail line construction sites. The estimated peak level of direct employment during 5 years of repository construction would be 1,035 workers. Current Nevada Test Site employees can ride DOE-provided buses to and from work; similarly, buses probably would be available for repository construction workers, which would reduce the number of vehicles traveling to the site each day by approximately a factor of 8. Table J-63 summarizes the anticipated number of traffic-accident-related injuries and fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be added congestion at the northwestern Las Vegas Beltway interchange with U.S. Highway 95. Current estimates call for traffic at this interchange during rush hours to be as high as 1,000 vehicles an hour (Clark County 1997, Table 3-12, page 3-43). The additional traffic from repository construction, an estimated 500 vehicles per hour, would add about 50 percent to traffic volume at peak rush hour and would contribute to congestion although congestion in this area would be generally low.

The average level of employment during repository operations would be about 2,700 workers. As mentioned above, DOE provides bus service from the Las Vegas area to and from the Nevada Test Site. Table J-63 summarizes the anticipated number of traffic-accident-related fatalities and the estimated consumption of gasoline that would occur from this travel activity. The greatest impact of this traffic would be increased congestion at the northwestern Las Vegas Beltway interchange with U.S. 95. As many as 500 vehicles an hour at peak rush hour would contribute to the congestion. Approximately

Table J-63. Health impacts from transportation of construction and operations workers.[a]

Phase	Kilometers[b] traveled (in millions)	Traffic fatalities	Fuel consumption (thousands of liters)[c]	Vehicle emissions-related fatalities
Construction	36.3 - 44.4	0.5 - 0.6	400 - 500	0.0026 - 0.0032
Operation and monitoring				
Emplacement and development	240 -300	3.2 - 4.0	2,600 - 3,300	0.017 - 0.022
Monitoring (76 years)	62.2	0.8	680	0.0045
Closure	20.2 - 42.7	0.3 - 0.6	220 - 470	0.0015 - 0.0031

a. Impacts are totals for 24 years for operations.

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

c. To convert liters to gallons, multiply by 0.26418.

150 people would be employed during monitoring and about 500 would be employed during closure. The number of vehicles associated with these levels of employment would contribute negligibly to congestion.

Table J-64 lists the impacts associated with the delivery of fabricated disposal container components from a manufacturing site to the repository. A total of 10,000 containers would be delivered; if a rail line to Yucca Mountain was not available, the mode of transportation would be a combination of rail and overweight truck. The analysis assumes that the capacity of each railcar would be two containers and that the capacity of a truck would be one container, so there would be 5,000 railcar shipments to Nevada and 10,000 truck shipments to the Yucca Mountain site. The analysis estimated impacts for one national rail route representing a potential route from a manufacturing facility to a Nevada rail siding. The analysis estimated the impacts of transporting the containers from this siding over a single truck route—the Apex/Dry Lake route analyzed for the transportation of spent nuclear fuel and high-level radioactive waste by heavy-haul trucks. Although the actual mileage from a manufacturing facility could be shorter, DOE decided to select a distance that represents a conservative estimate [4,439 kilometers (2,758 miles)]. The impacts are split into two subcategories—health effects from vehicle emissions and fatalities from transportation accidents.

Table J-64. Impacts of disposal container shipments for Proposed Action.[a]

Type of shipment	Number of shipments	Vehicle emissions-related health effects	Traffic fatalities
Rail and truck	5,000 rail/10,000 truck	0.14	0.8

a. Impacts are totals for 24 years of operations.

Air Quality

The exhaust from vehicles involved in the transport of personnel and materials to the repository would emit carbon monoxide, nitrogen dioxide, and particulate matter (PM_{10}). Because carbon monoxide is the principal pollutant of interest for evaluating impacts caused by motor vehicle emissions, the analysis focused on it.

The analysis assumed that most of the personnel who would commute to the repository would reside in the Las Vegas area and that most of the materials would travel to the repository from the Las Vegas area. To estimate maximum potential emissions to the Las Vegas Valley airshed, which is in nonattainment for carbon monoxide (FHWA 1996, pages 3-53 and 3-54), the analysis assumed that all personnel and material would travel from the center of Las Vegas to the repository. Table J-65 lists the estimated annual amount of carbon monoxide that would be emitted to the valley airshed during the phases of the repository project and the percent of the corresponding threshold level.

As listed in Table J-65, the annual amount of carbon monoxide emitted to the nonattainment area would be below the threshold level during all phases of the repository. In the operation phase, the estimated annual amount of carbon monoxide emitted would be close (93 percent) to the threshold level. So, a more

Table J-65. Annual amount of carbon monoxide emitted to Las Vegas Valley airshed from transport of personnel and material to repository (kilograms per year)[a] for the Proposed Action.

Phase	Annual emission rate	GCR threshold level[b]
Construction	47,000	51
Operation and monitoring		
Operation period	85,000	93
Monitoring period	6,700	7.4
Closure	17,000	19

a. To convert kilograms to tons, multiply by 0.0011023.
b. GCR = General Conformity Rule emission threshold level for carbon monoxide is 91,000 kilograms (100 tons) per year.

detailed analysis and conformity analysis might be required to determine if mitigation would be needed to ensure that the additional emissions did not impede efforts in Nevada to bring the Las Vegas area into attainment for carbon monoxide.

For areas that are in attainment, pollutant concentrations in the ambient air probably would increase due to the additional traffic but, given the relatively small amount of traffic that passes through these areas, the additional traffic would be unlikely to cause the ambient air quality standards to be exceeded.

Noise

Traffic-related noise on major transportation routes used by the workforce would likely increase. The analysis of impacts from traffic noise assumed that the workforce would come from Nye County (20 percent) and Clark County (80 percent). During the period of maximum employment in 2015, an estimated daily maximum of 576 vehicles would pass through the Gate 100 entrance at Mercury during rush hour (DOE 1996c, page 4-45), compared to a baseline of 232 vehicles per hour. This would result in an increase in rush hour noise from 65.5 dBA to 69.5 dBA for the communities of Mercury and Indian Springs. The 4.4-dBA increase could be perceptible to the communities but, because of the short duration, would be unlikely to result in an adverse response.

J.3.6.2 Impacts of Transporting Wastes from the Repository

During repository construction and operations, DOE would ship waste and sample material from the repository. The waste would include hazardous, mixed, and low-level radioactive waste. Samples would include radioactive and nonradioactive hazardous materials shipped to laboratories for analysis. In addition, nonhazardous solid waste could be shipped from the repository site to the Nevada Test Site for disposal. However, as noted in Chapter 2, DOE proposes to include an industrial landfill on the repository site. Table J-66 summarizes the maximum quantities of waste (generally from the uncanistered packaging scenario and the low thermal load scenario) that DOE would ship from the repository and the number of truck shipments.

Occupational and Public Health and Safety

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small and would present little risk to public health and safety. This waste could be shipped by rail (if DOE built a rail line to the repository site) or by legal-weight truck to permitted disposal facilities. The principal risks associated with shipments of these materials would be related to traffic accidents. These risks would include 0.01 fatality for the combined construction, operation and monitoring, and closure phases for hazardous wastes.

DOE probably would ship low-level radioactive waste by truck to existing disposal facilities on the Nevada Test Site. Although these shipments would not use public highways, DOE estimated their risks. As with shipments of hazardous waste, the principal risk in transporting low-level radioactive waste would be related to traffic accidents. Because traffic on the Nevada Test Site is regulated by the Nye County Sheriffs Department, DOE assumed that accident rates on the site are similar to those of secondary highways in Nevada. Low-level radioactive waste would not be present during the construction of the repository. Therefore, accidents involving such waste could occur only during the

Table J-66. Shipments of waste from the Yucca Mountain Repository.[a]

	Construction		Operation and monitoring		Closure	
Waste	Volume (cubic meters)[b]	Number of shipments	Volume (cubic meters)	Number of shipments	Volume (cubic meters)	Number of shipments
Hazardous[c]	990	60	6,100	340	630	8
Low-level radioactive[d]	0	0	68,000	1,800	3,500	2
Dual-purpose canisters[e]	0	0	30,000	6,600	0	0
Mixed[c]	0	0	23	2	0	0
Nonhazardous solid[f,g]	13,000	120	90,000	810	160,000	1,400

a. Source: Chapter 4, Section 4.1.12.
b. To convert cubic meters to cubic yards, multiply by 1.3079.
c. Shipment numbers based on 16.64 cubic meters per shipment.
d. Shipment numbers based on 38 cubic meters per shipment.
e. Shipment numbers based on 23 metric tons per shipment.
f. Shipment numbers based on cubic meters per shipment.
g. Includes construction and demolition debris and sanitary and industrial solid waste.

operation and monitoring and the closure phases, although most of this waste would be generated during the operation and monitoring phase. DOE estimates 0.05 traffic fatality from the transportation of low-level radioactive waste during the repository operation and monitoring and closure phases.

Air Quality

The quantities of hazardous waste that DOE would ship to approved facilities off the Nevada Test Site would be relatively small. Vehicle emissions due to these shipments would present little risk to public health and safety.

Biological Resources and Soils

The transportation of people, materials, and wastes during the construction, operation and monitoring, and closure phases of the repository would involve more than 1.6 billion vehicle-kilometers (1 billion vehicle-miles) of travel on highways in southern Nevada. This travel would use existing highways that pass through desert tortoise habitat. Individual desert tortoises probably would be killed. However, because populations of the species are low in the vicinity of the routes (Bury and Germano 1994, pages 57 to 72), few would be lost. Thus, the loss of individual desert tortoises due to repository traffic would not be likely to be a threat to the conservation of this species. In accordance with requirements of Section 7 of the Endangered Species Act, DOE would consult with the Fish and Wildlife Service and would comply with mitigation measures resulting from that consultation to limit losses of desert tortoises from repository traffic.

J.3.6.3 Impacts from Transporting Other Materials and People in Nevada for Inventory Modules 1 and 2

The analysis evaluated impacts to occupational and public health and safety in Nevada from the transport of materials, wastes, and workers (including repository-related commuter travel) for construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of materials in Inventory Modules 1 and 2. The analysis assumed that the routes and transportation characteristics (for example, accident rates) for transportation associated with the Proposed Action and Inventory Modules 1 and 2 would be the same. The only difference would be the projected number of trips for materials, wastes, and workers traveling to the repository.

Table J-67 lists estimated incident-free (vehicle emissions) impacts and traffic (accident) fatality impacts in Nevada for the transportation of materials, wastes, and workers (including repository-related commuter travel) for the construction, operation and monitoring, and closure of the repository that would occur for the receipt and emplacement of the materials in Inventory Modules 1 and 2.

Table J-67. Impacts from transportation of materials, consumables, personnel, and waste for Modules 1 and 2.[a]

Category	Kilometers traveled[b]	Fatalities	Emission-related health effects
Materials	90 - 160	1.7 - 2.9	0.07 - 0.01
Personnel	490 - 650	4.9 - 6.5	0.04 - 0.05
Waste material (Module 1/Module 2)			
Hazardous	0.17/0.20	0.018/0.021	0.00001/0.00001
Low-level radioactive	0.75/0.86	0.10/0.12	0.001
Nonhazardous solid	0.66	0.066	0.00005
Dual-purpose canisters	35	1.5	0.24

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.

Even with the increased transportation of the other materials included in Module 1 or 2, DOE expects that the transportation of materials, consumables, personnel, and waste to and from the repository would be minor contributors to all transportation on a local, state, and national level. Public and worker health impacts would be small from transportation accidents involving nonradioactive hazardous materials. On average, in the United States there is about 1 fatality caused by the hazardous material being transported for each 30 million shipments by all modes (DOT 1998a, page 1; DOT undated, Exhibit 2b).

J.3.6.4 Environmental Justice

The impacts of transporting people and materials other than spent nuclear fuel and high-level radioactive waste would be small and random. Because the number of shipments and commuter trips would be small in comparison to other commercial and commuter travel in southern Nevada and would use existing transportation facilities in the area, impacts to land use; air quality; hydrology; biological resources and soils; occupational and public health and safety; cultural resources; socioeconomics; noise; aesthetics; utilities, energy, and materials; and waste management would be small. In addition, due to the nearly random nature of accidents that would involve the transportation of materials and people, the probability of such an accident would be small in any location, minimizing the risk at a specific location. Furthermore, because potential accidents would be nearly random, impacts to minority or low-income populations and to Native Americans along the routes in Nevada would be unlikely to be disproportionately high and adverse.

Because there would be no adverse or disproportionate impacts from transportation of people and materials, a detailed environmental justice study is not required.

J.3.6.5 Summary of Impacts of Transporting Other Materials

Table J-68 summarizes the impacts of transporting other materials to the repository site for the Proposed Action.

Table J-68. Health impacts from transportation of materials, consumables, personnel, and waste for the Proposed Action.[a]

Category	Distance traveled (kilometers)[b]	Impact
Human health and safety		
Construction		
Materials	8,200,000 - 9,900,000	0.14 - 0.17 fatality
Personnel	36,300,000 - 44,400,000	0.5 - 0.6 fatality
Waste		
Hazardous	14,500	0.002 fatality
Low-level waste	--[c]	--
Nonhazardous	29,000	0.003 fatality
Canisters	--	--
Operation and monitoring		
Materials	57,000,000 - 94,000,000	1.0 - 1.6 fatalities
Personnel	300,000,000 - 360,000,000	4.0 - 4.8 fatalities[d]
Waste		
Hazardous	90,000	0.002 fatality
Low-level waste	435,000	0.008 fatality
Nonhazardous	196,000	0.003 fatality
Canisters	1,590,000	0.028 fatality
Closure		
Materials	4,400,000	0.1 fatality
Personnel	20,200,000 - 42,700,000	0.3 - 0.6 fatality
Waste		
Hazardous	9,200	0.001 fatality
Low-level waste	22,200	0.002 fatality
Nonhazardous	338,000	0.04 fatality
Canisters	0	--
Air quality		
Construction traffic	74,000,000	75 percent of Air Quality General Conformity Rule threshold for PM_{10}
Operation and monitoring traffic		
Operations	860,000,000	170 percent of carbon monoxide threshold
Monitoring	170,000,000	9 percent of carbon monoxide threshold
Closure traffic	1,000,000,000	30 percent of carbon monoxide threshold
Biological resources	1,000,000,000	Individual desert tortoises would be killed but kills would not be likely to be a threat to conservation of species
Noise	--	Small impacts unlikely to affect communities
Environmental justice	--	Traffic impacts unlikely to be high and disproportionate for minority or low income populations or populations of Native Americans

a. Numbers are rounded.
b. To convert kilometers to miles, multiply by 0.62137.
c. -- = none.
d. Monitoring for 76 years.

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