The Projected Environmental Impacts of Transportation of Radioactive Material to the First United States Repository Site – An Overview

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Abstract
The relative national environmental impacts of transporting spent fuel and other nuclear wastes to each of 9 candidate repository sites in the United States were analyzed for the 26-year period of repository operation. Two scenarios were examined for each repository: 1) shipment of 5-year-old spent fuel and Defence High-Level Waste (DHLW) directly from their points of origin to a repository (reference case); 2) shipment of 5-year-old spent fuel to a Monitored Retrievable Storage (MRS) facility and shipment (by dedicated rail) of 10-year-old consolidated spent fuel from the MRS to a repository. Transport by either all truck or all rail from the points of origin were analyzed as bounding cases. The computational system used to analyze these impacts included the WASTES II logistics code and the RADTRAN III risk analysis code. The radiological risks for the reference case increased as the total shipment miles to a repository increased for truck; the risks also increased with mileage for rail but at a lower rate. For the MRS scenario the differences between repository sites were less pronounced for both modal options, because of the reduction in total shipment miles possible with the large dedicated rail casks. All the risks reported are small in comparison to the radiological risks due to 'natural background.'

Résumé
L'impact relatif sur l'environnement du transport du combustible épuisé et des autres déchets nucléaires jusqu'aux neuf sites susceptibles d'être choisis comme dépôts aux États-Unis a été étudié. Deux scénarios ont été envisagés pour chacun de ces sites: 1) combustible épuisé vieux de 5 ans et déchets de haute activité provenant des armes nucléaires expédiés directement de leurs points d'origine jusqu'aux sites (cas de référence); 2) combustible épuisé vieux de 5 ans expédié possibilité de reprise et combustible épuisé consolidé vieux de 10 ans expédié (par voie ferrée réservée) des installations de stockage contrôlé avec possibilité de reprise jusqu'à un site. Le transport par camion ou par wagon à partir des points d'origine a servi de cas limite. Le système informatique utilisé pour analyser cet impact était constitué du code logistique WASTES II et du code d'évaluation des risques RADTRAN III. Dans le cas de l'expédition par camion, les risques radiologiques du cas de référence augmentent avec la distance totale en milles jusqu'au site du dépôt; les risques augmentent aussi avec le transport par wagon, mais às un rythme plus lent, toutefois. En ce qui a trait au deuxième scénario, les différences entre les sites des deux options modales sont moins accentuées en raison de la réduction du nombre total de milles parcourus avec les châsteaux sur voie ferrée réservée. Tous les risques signalés sont faibles comparativement à un 'milieu naturel.'

Introduction

Spent fuel from commercial nuclear power reactors in the United States will be permanently disposed of in mined geologic repositories. The Nuclear Waste Policy Act (NWPA) of 1982 outlined the implementation of this approach by the US Department of Energy (DOE). The DOE has begun selection of a site for a first repository from among 9 candidate sites in 3 geologic media – salt, tuff, and basalt. A monitored retrievable storage (MRS) facility may be included in the system; spent fuel could be stored for up to 5 years at an MRS, which would also consolidate the fuel before shipping it to the repository.

This paper reviews the analysis of the relative national environmental impacts of transporting nuclear wastes to each of the 9 candidate repository sites in the United States [Cashwell 1986]. This analysis was performed to support the repository environmental assessments, which were used as input to the selection of three priority sites. The sites selected for further

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characterization were the Permian Basin in Texas; Yucca Mountain, Nevada; and Hanford, Washington.

Several of the potential sites were closely clustered and, for the purpose of distance and routing calculations, were treated as a single location. These are: Cypress Creek Dome and Richton Dome in Mississippi (Gulf Interior Region), Deaf Smith County and Swisher County sites in Texas (Permian Basin), and Davis Canyon and Lavender Canyon sites in Utah (Paradox Basin). The remaining sites are: Vacherie Dome, Louisiana; Yucca Mountain, Nevada; and Hanford Reservation, Washington.

For compatibility with both the repository system authorized by the NWPA and with the MRS option, 2 separate scenarios were analyzed. In brief, they are 1) shipment of spent fuel and high-level waste (HLW) directly from waste generators to a repository (reference case), and 2) shipment of spent fuel to a MRS facility, and then to a repository.

Problem Definition

In order to perform comparative cost and risk analyses of the impacts of transportation for a future US nuclear waste management system, a large array of data is required. These data include information on the transport links and surrounding populations, routing information (e.g., distances traveled), packaging (e.g., cask capacity), transport mode characteristics (e.g., train speeds), radionuclide inventory, and pertinent operational characteristics of the system, such as accident rates. These data are used as input for 2 major computational tools, the WASTES II logistics code and the RADTRAN III risk analysis code.

For the reference case, the primary waste stream is spent nuclear fuel (SF) from reactors. Secondary waste streams considered for this case include defence high-level wastes (DHLW) from the Savannah River Plant in South Carolina, the Hanford Reservation in Washington, and the Idaho National Engineering Laboratory in Idaho; and commercially generated high-level waste from West Valley, New York (WVHLW). Acceptance of DHLW in a commercial repository was endorsed by the President of the United States in 1985 [White House Memorandum 1985]. In this case, all reactors will ship 5-year-old, or older, unconsolidated spent fuel directly to a candidate repository site over a 26-year period. High-level commercial and defence wastes will also be shipped directly to the repository. Two primary modal options are examined for the Reference Case: all truck and all rail from reactors and HLW generators. The resultant costs and risks will bound the transportation impacts. No attempt has been made to forecast the actual fractions of truck and rail transport that might be used. The shipping system ultimately used for transportation of spent fuel and HLW will be a combination of modes determined by considerations such as the capabilities of handling facilities at the origins, freight rates, and operational constraints of the system.

MRS input data and scenarios are compatible with those being used by the MRS program. Final MRS documentation to be presented to Congress will, however, include additional alternatives not discussed here.

For the MRS cases, as in the reference case, reactors will ship 5-year-old, or older, unconsolidated spent fuel, but to an MRS rather than a repository. All spent fuel leaving the MRS will be consolidated and at least 10 years old. Additional secondary wastes would be generated at an MRS by the proposed spent fuel consolidation and possible overpacking operations, and would also be shipped to the repository. These secondary wastes would consist of assembly hardware, high-activity waste (HAW), and transuranic waste (TRU). Transport from an MRS would be by one of two possible shipping options: 1) 100-ton (100T) dedicated rail shipments of overpacked consolidated spent fuel and waste byproducts generated in the consolidation process, and 2) 150-ton (150T) dedicated rail shipments of non-overpacked consolidated spent fuel and byproducts. As in the reference case, high-level commercial and defence wastes are shipped directly to the repository. For shipments from the MRS, bounding values for total cask weight and payload characteristics were used either to minimize or to maximize cask capacity and, hence, to put upper and lower limits on the number of shipments from the MRS to the repository.

Methodology

In order to perform cost and risk analyses of the impacts of transportation, a number of assumptions must be made regarding the physical, operational, and geographical characteristics of the system to be analyzed over the time period assumed for operations. For this reason, many of the analyses performed to provide the systems simulations required by the National Environmental Policy Act or the Nuclear Waste Policy Act are comparative in nature during the EA stage. An increasing level of specificity will be required for the final environmental impact statement, as well as for actual budgeting and operational forecasting.

Figure 1 outlines the basic structure of models and data-base input necessary to perform a national transportation cost and risk analysis. The major components of this modeling system are discussed below.

Spent fuel data base – This documents utility responses to a voluntary survey on spent-fuel-discharge rates, storage-pool capacities, and anticipated future operational plans; compiled by Battelle Pacific Northwest Laboratories for the DOE [Heeb 1985].

Electric generating capacity data – The Energy Information Administration (EIA), a branch of the DOE, predicts the anticipated future industry requirements and capabilities by fuel source type, by year [Gieleki 1984].

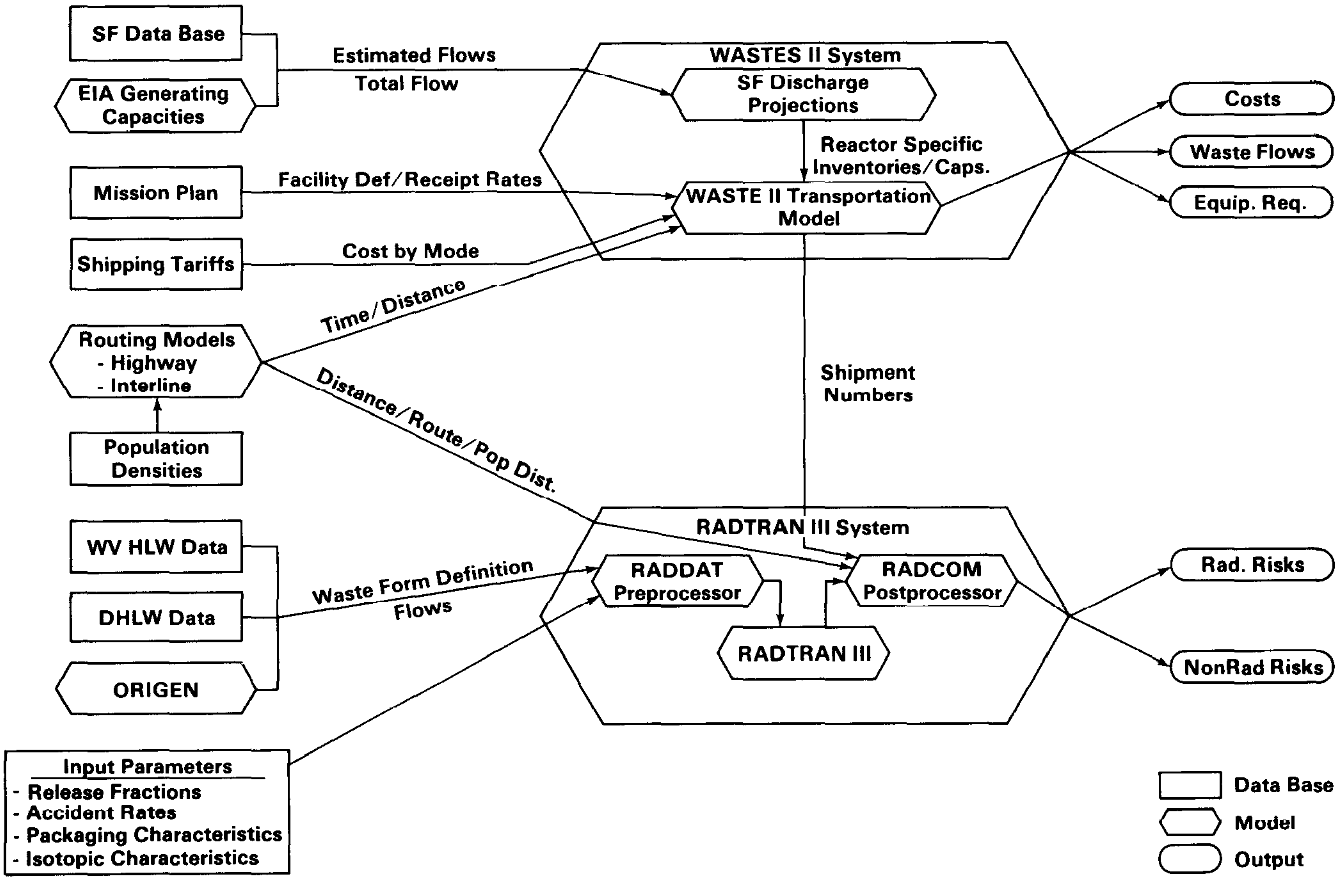

Figure 1 Computational system used in the analysis.

Spent fuel discharge projections – Based upon the spent fuel data base, as adjusted to conform to the EIA mid-case; anticipated waste flows from reactors were calculated [Heeb 1985].

DOE / Office of Civilian Radioactive Waste Management Mission Plan – Anticipated overall receipt rates of spent fuel and HLW at the first repository are furnished in tabular form in this document [DOE Mission Plan 1985]. These data were used to assign priorities to the projected flows discussed above.

Shipping tariffs – Published shipping tariffs are used to calculate the relative costs of transport for a given mode and distance [McNair 1986].

DOE / West Valley waste form definition – The characteristics of the WV commercial high-level waste form [Rykken 1985].

DOE / defence programs HLW waste form definition – Projections of waste-form characteristics for DHLW generated in support of US Defence programs [Baxter 1983].

ORIGEN – Computer code developed to provide the waste-form characteristics of spent nuclear fuel over time [Croff 1980].

HIGHWAY – This routing model is based upon a coded network of the nation's highways. It calculates a travel path, distance, and time for any given origin-destination pair. Both HIGHWAY and INTERLINE require input of all waste shipping (origin) and receiving (destination) facility locations [Joy 1982].

INTERLINE – The INTERLINE model calculates the railroad route and distance between any given origin-destination pair [Peterson 1985].

USGS population density profiles – Use of the US Census Bureau's population characteristics, together with the routes calculated above, permit population densities along the prospective travel routes between each origin-destination pair to be determined.

WASTES – The WASTES model is a simulation-language based model for estimating flows, equipment requirements, inventories, and costs of wastes for a user-defined system. The model requires origin-specific data such as system shipping priorities, storage constraints, distance to receiving facility, and operational parameters specific to the modal assumptions input; WASTES calculates the logistics of the necessary material movements outlined above [Shay 1986].

RADDAT – A computerized preprocesser for input parameters and data for RADTRAN. This code maintains an internal library of radioisotope characteristics which are automatically called and formatted for a given waste form.

Table 1: Total Shipment-Miles (Millions of Miles*) Reference Case – Direct to Repository

Mode / waste type	Repository location GIR	Vacherie	Permian	Paradox	Yucca Mt	Hanford
100% Truck						
SF	67.4	71.7	94.4	115.1	141.8	149.7
DHLW	28.0	28.0	26.0	28.0	33.0	35.0
WVHLW	1.0	1.0	1.0	2.0	2.0	2.0
Total	96.4	100.7	121.4	145.1	176.8	186.7
100% Rail						
SF	11.0	11.7	15.4	18.8	23.2	24.6
DHLW	6.5	6.5	6.1	6.5	7.6	8.4
WVHLW	0.2	0.2	0.2	0.2	0.3	0.3
Total	17.7	21.2	21.7	25.5	31.1	33.3

*1 mile = 1.608 km.

RADTRAN – This model calculates the radiological risks associated with the transport of radioactive materials. Although RADTRAN may be used alone for simple calculations, it is used within the computational system described here to generate unit risk factors (i.e., the risks associated with the transport of 1 shipment over 1 unit of distance in each population-density zone) [Madson 1986]. Separate unit-risk factors are generated for incident-free non-occupational risk, incident-free occupationasl risk, and accident risk for each shipment type in each population density zone. Incident-free non-occupational risk includes risks to persons at stops, persons residing within 800 m of the transport link, and persons sharing the transport link. Incident-free occupational risk includes risk to crew, rail inspectors, etc. Doses for these calculations are based on the maximum regulatory transport index. The accident unit risk is calculated after the basic accident rate is partitioned according to fractional occurrence by population density zone. Fractional occurrence by severity is then accounted for in a severity category matrix. For spent fuel, 6 severity categories were used. Releases may occur in categories III–VI. Release fraction estimates are taken from Wilmot (1981). Exposure pathways included are direct inhalation, cloudshine, groundshine, inhalation of resuspended material, and ingestion.

RADCOM – Combines the unit risk factors from RADTRAN with the numbers of shipments and total distances traveled in each population-density zone, and then sums the terms to calculate total radiological risks. Nonradiological unit risk factors from other sources [National Transportation Statistics 1985] are calculated in a similar manner to determine the total nonradiological risks.

The interactions of these models, as applied to the user-defined input assumptions for the system to be analyzed, allow national transportation costs and risks to be compared for the scenarios of interest to the repository program.

Results

Results of the analysis performed for the reference case are summarized in Tables 1–3, below. The differences in cost and impacts among the various repository sites are related primarily to the total shipping distances (Table 1). As can be noted from the table, spent fuel shipments account for the largest fraction of the total shipping distance for both modal options, comprising from 70–80 per cent of the total truck travel, and from 62–75 per cent of the total rail travel. In either case, the largest percentages are associated with travel to the most western site (Hanford, Washington). The fraction of total travel attributable to spent fuel trans-

Table 2: Total Transportation Costs ($M) Reference Case – Direct to Repository

Mode / waste type	Repository location GIR	Vacheria	Permian	Paradox	Yucca Mt	Hanford
100% Truck						
Capital	227.2	234.2	261.2	290.1	325.1	337.2
Operating	708.9	730.0	866.0	1015.1	1213.6	1277.8
Total	936.1	964.2	1127.2	1305.2	1538.7	1615.0
100% Rail						
Capital	267.3	277.7	300.9	322.5	354.2	362.8
Operating	714.7	734.9	821.6	885.3	991.0	1013.8
Total	982.0	1012.6	1122.5	1207.8	1345.2	1376.6

Table 3: Summary of the Total Risks of Transportation Reference Case – Direct to Repository

	Repository					
Mode	*GIR*	*Vacherie*	*Perimian*	*Paradox*	*Yucca Mt*	*Hanford*
100% truck from origin						
SF						
Radiological[1]	4.6	5.0	6.2	7.7	9.2	10
Nonradiological[2]	13	14	18	24	29	31
HLW						
Radiological	1.8	1.7	1.7	1.8	2.1	2.1
Nonradiological	6.2	5.8	6.2	6.1	7.4	7.4
100% rail from origin						
SF						
Radiological	.16	.17	.18	.21	.24	.25
Nonradiological	.81	.85	1.0	1.3	1.6	1.6
HLW						
Radiologica	.062	.067	.063	.066	.079	.074
Nonradiological	.63	.69	.64	.66	.84	.79
Totals						
Truck from origin:						
Radiological	6.4	6.7	7.9	9.5	11	12
Nonradiological	19	20	24	30	36	38
Rail from origin:						
Radiological	.22	.24	.24	.28	.32	.32
Nonradiological	1.4	1.5	1.6	2.0	2.4	2.4

[1] Radiological health effects include latent cancer fatalities and genetic effects in all generations.
[2] Nonradiological fatalities.

port increases as the potential repository site is shifted to the west, because most of the spent fuel inventory projected to require shipment to the first repository is from reactors in the eastern United States. The relative contribution of high-level wastes requiring shipment to the repository is between 19 and 29 per cent for truck, and 25 and 37 per cent for rail. Although the projected mileage increases as the more western repository options are analyzed, the relative influence of high-level wastes on the results decreases. Data in Table 1 indicate that miles traveled to the westernmost sites (Yucca Mt, Nevada, and Hanford, Washington) are almost double the total shipment miles required for transport to the easternmost sites in the Gulf Interior Region (GIR).

Transportation costs for the repository location options are summarized in Table 2. These costs increase with the total number of shipment-miles; however, because of the tariff structures of the transport modes, they do not increase in a linear manner. Truck costs increase by approximately 75 per cent between the most eastern site in the GIR and the Hanford site in the West. Consistent with the rail rate structure, total rail costs for these sites vary by only about 40 per cent. Truck costs are lower than rail for the easternmost sites and higher than rail for the western sites. The contribution of spent fuel cost to the total is consistent with the fraction of shipment mileage attributable to spent fuel transport for truck; it is somewhat less than the fraction of total mileage for rail.

Because the points of origin of most shipments (i.e., reactors) are primarily in the eastern United States, the average fractions of total travel in rural, suburban, and urban population-density zones are about the same for spent fuel transport to each candidate repository site. Consequently, total travel distance becomes the major discriminator of risk between sites for a given shipment scenario. Table 3 shows that the GIR and Vacherie, Louisiana, sites, which are closest to the origin points, have the lowest overall risks associated with them; while those sites farthest from the majority of the country's reactors have the highest associated risks. However, the total risks associated with the closest repository sites only differ from those for the most distant site by about a factor of 1.9 to 2.1, for truck, and by about a factor of 1.5 to 1.8 for rail. These factors generally parallel increases in shipment-miles, except for the radiological risk of rail transport, which increases at a significantly lower rate than the mileage. A component of radiological risk for rail transport, but not for truck transport, is associated with required endpoint classification and inspection stops. Because this component is distance-independent (i.e., the same for all trips, short or long), the influence of distance traveled on total radiological risk for rail is less pronounced than for truck.

Insertion of an MRS into the system tends to reduce the variation in cost and risk between the potential repository sites, because of the reduction in shipment-miles possible with the large dedicated rail casks. The 100T cask can carry between 18 and 45 consolidated, canistered spent fuel assemblies; the 150T cask capaci-

Table 4: Total Shipment-Miles (Millions of Miles) MRS Case – MRS at Oak Ridge

	Repository location					
Mode / waste typer	*GIR*	*Vacherie*	*Permian*	*Paradox*	*Yucca Mt*	*Hanford*
Truck from origin						
SF to MRS	48.8	48.8	48.8	48.8	48.8	48.8
DHLW to Repos.	28.0	28.0	26.0	28.0	33.0	35.0
WVHLW to Repos.	1.0	1.0	1.0	2.0	2.0	2.0
Rail from Origin						
SF to MRS	8.0	8.0	8.0	8.0	8.0	8.0
DHLW to Repos.	6.5	6.5	6.1	6.5	7.6	8.4
WVHLW to Repos.	0.2	0.2	0.2	0.2	0.3	0.3
Rail from MRS to Repository (150T, nonoverpacked SF)	0.2	0.3	0.6	0.8	1.5	1.0
Totals						
Truck from origin:						
150T from MRS	78.0	78.1	76.4	78.6	85.3	86.8
Rail from origin:						
150T from MRS	14.9	15.0	14.9	15.5	17.4	17.7

ty is between 48 and 171 assemblies. The actual payload depends on the fuel type (boiling water reactor (BWR) or pressurized water reactor (PWR)) and the geologic medium of the repository, because the consolidated fuel is packaged differently according to whether the repository is developed in salt, tuff, or basalt. Further, the MRS also reduces the difference in costs and risks between modal options from the reactors and high-level-waste sites. Shipments from origin sites to the MRS dominate the total transportation-related impacts. The 150T rail cask in particular reduces the impacts of transportation from the MRS to the repository because of its large payload per shipment.

Use of repository-specific canisters and overpacks for the MRS cases influences the relative ranking of the Yucca Mountain (tuff) and the Hanford (basalt) repository sites, because the canister and overpack for tuff are lower in capacity than the canister and overpack for basalt (all of the other sites use the canister and overpack for salt). In addition, the projected rail routings between the MRS locations and Yucca Mountain are more circuitous than the rail routings between the MRS locations and Hanford. The combination of increased shipment-miles and reduced canister and overpack capacities causes Yucca Mountain to rank higher in cost and risk than the Hanford repository site. Tables 4–6 summarize the shipment-miles, costs, and risks for the MRS case for a MRS located in Oak Ridge, Tennessee, with 150T dedicated rail casks between the MRS and the repository.

Summary

To summarize, transportation costs increase with the

Table 5: Total Transportation Costs ($M)[1] MRS Case – MRS at Oak Ridge

	Repository location					
Mode / waste type	*GIR*	*Vacherie*	*Permian*	*Paradox*	Yucca Mt	*Hanford*
Truck from reactors, HLW Sites						
Capital	201.0	202.1	204.3	209.8	214.2	217.5
Operating	613.7	608.1	601.1	615.8	639.0	652.9
Rail from reactors, HLW Sites						
Capital	232.3	237.7	235.9	239.5	246.7	250.3
Operating	643.7	646.1	647.5	644.2	667.9	664.4
Rail from MRS to repository (150 T, nonoverpacked)						
Capital	78.6	78.6	78.6	78.6	100.6	84.1
Operating	172.7	199.0	265.3	306.8	468.7	346.8
Totals						
Truck from origin:						
150T from MRS	1066.0	1087.8	1149.3	1211.0	1422.5	1301.3
Rail from origin:						
150T from MRS	1127.3	1161.4	1227.3	1269.1	1483.9	1345.6

[1] The totals presented in this table are for the case in which all spent fuel and HLW wastes are shipped by the mode indicated; dedicated rail shipments from the MRS to the repository are added.

Table 6: Summary of the Risks of Transportation of Spent Fuel and High-Level Wastes: MRS Case – (All SF to MRS, 150T Cask)

	Repository					
Mode	*GIR*	*Vacherie*	*Permian*	*Paradox*	*Yucca Mt*	*Hanford*
100% truck from origin						
SF						
Radiological[1]	3.6	3.6	3.6	3.6	3.6	3.6
Nonradiological[2]	9.1	9.1	9.1	9.1	9.1	9.1
HLW						
Radiological	1.8	1.7	1.7	1.8	2.1	2.1
Nonradiological	6.2	5.8	6.2	6.1	7.4	7.4
1-% rail from origin						
SF						
Radiological	.14	.14	.14	.14	.14	.14
Nonradiological	.92	.92	.92	.92	.92	.92
HLW						
Radiological	.062	.067	.063	.066	.079	.074
Nonradiological	.63	.69	.64	.66	.84	.79
150T rail from MRS						
Radiological	.017	.035	.035	.038	.054	.042
Nonradiological	1.4	2.6	3.8	5.3	1.0	6.1
Totals						
Truck from origin:						
150T from MRS						
Radiological	5.4	5.3	5.3	5.4	5.8	5.7
Nonradiological	17	18	19	20	26	22
Rail from origin:						
150T from MRS						
Radiological	.22	.25	.24	.25	.27	.26
Nonradiological	2.9	4.2	5.3	6.9	12	7.7

[1] Radiological health effects include latent cancer fatalities and genetic effects in all generations.
[2] Nonradiological fatalities.

total number of shipment-miles; however, because of the tariff structures of the transport modes, they do not increase in a linear manner. Truck costs increase by approximately 75 per cent between the most eastern site in the Gulf Interior Region and the Hanford site in the West. Consistent with the rail rate structure, total rail costs for these sites vary by only about 40 per cent. Truck costs are lower than rail for the easternmost sites and higher than rail for the western sites. The contribution of spent fuel cost to the total is consistent with the fraction of shipment mileage attributable to spent fuel transport for truck; it is somewhat less than the fraction of total mileage for rail.

Between 17 and 38 truck accident fatalities, between 1.4 and 7.7 rail accident fatalities, and between 0.22 and 12 radiological health effects can be expected to occur as a result of radioactive material transportation during the 26-year operating period of the first repository. During the same period in the United States, about 65,000 total deaths from truck accidents and about 32,000 total deaths from rail accidents would occur; also an estimated 58,300 cancer fatalities are predicted to occur in the United States during a 26-year period from exposure to background radiation alone (not including medical and other man-made sources) [Oakley 1972]. The risks reported here are upper limits and are small by comparison with the 'natural background' of risks of the same type.

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