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A Preliminary Analysis of the Cost and Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites

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Abstract

This report documents preliminary cost and risk analyses that were performed in support of the Nuclear Waste Terminal Storage program. The analyses compare the costs and hazards of transporting wastes to each of five regions that contain potential candidate nuclear waste repository sites being considered by the NWTS program. Two fuel-cycle scenarios were analyzed: once-through and reprocessing. Transportation was assumed to be either entirely by truck or entirely by rail for each of the scenarios. The results from the risk analyses include those attributable to nonradiological causes and those attributable to the radioactive character of the wastes being transported.

Acknowledgments

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Executive Summary

This document is a first attempt to bring together information about the costs and risks of transporting nuclear wastes to potential candidate commerical repository sites. It will be used to support the environmental assessments that are required at this stage of repository site selection. Since values presented herein are thought to be based on data that will produce cost and risk estimates greater than those that might actually occur, this document may be useful to assess whether or not any of the sites may pose unacceptable risks and should be disqualified now before being evaluated further. It is important to remember that transportation is but one element used to determine site acceptability. As long as the transportation impacts for any site are not unacceptably high, they should not be viewed out of context of all other impacts that the repository may have on the environment. Another important result of this report will be to put into focus areas related to transportation of waste that should be looked at more closely during the period between preparing the environmental assessments and the environmental impact statements.

Each of five potential candidate repository sites was evaluated in this document for its potential resultant costs and risks related to transportation should it be selected. For purposes of analysis, an hypothetical repository was assumed to be located at each of the five potential candidate repository sites. The evaluation considered two scenarios: the once-through fuel cycle in which no reprocessing was assumed and the reprocessing fuel cycle. The reprocessing site considered was located at Barnwell, SC. Its location is shown in Figure 1 along with the five potential candidate repository sites: The Gulf Interior Region, the Permian Basin, the Paradox Basin, Yucca Mountain, and Hanford. Two other sites are located on the map: West Valley Plant and Savannah River Plant; these two sites also were assumed to send waste to a repository. The two scenarios and their associated waste streams are depicted in Figure 2. In the once-through fuel cycle, the reactor operators were assumed to send their spent fuel (SF) directly to the repository; West Valley and Savannah River also were assumed to send their high-level waste (WVHLW and DHLW) to the repository. The reprocessing scenario interposes another transportation step. Instead of sending their spent fuel to a repository, the reactor (commercial) operators send the spent fuel to the reprocessing plant where four types of waste are generated from it that must be sent to the repository: contact-handled transuranic (CHTRU) waste, remotely handled transuranic (RHTRU) waste, cladding hulls, and commercial high-level waste (CHLW). Savannah River and West Valley wastes were considered again in this scenario. The amount of additional wastes generated during reprocessing has an important effect on transportation cost and risk. Since the reprocessing information is not currently well defined, conclusions comparing impacts of reprocessing and the once-through fuel-cycle should be made only with great caution and with an understanding of the underlying assumptions made.

Common to both cost and risk assessment is the need to define the number of waste shipments and the distance that must be traveled. The key parameter is the capacity of the repository, which for this analysis was assumed to be 72 000 tHM (tonnes of heavy metal) of spent fuel or the waste from reprocessing that amount of spent fuel. This value is slightly higher (2000 tHM) than the value specified in the Nuclear Waste Policy Act (Public Law 97-425) and was used because much of this analysis was completed prior to signing the Act into law. The quantities of waste from Savannah River and West Valley were independent of this value and required additional repository capacity. Table 1 contains the total number of shipments assumed for each waste type. Each scenario was evaluated, assuming that all shipments would be made entirely by truck or entirely by rail. In order to produce this table, assumptions about the capacities of the transport packagings had to be made. At this time, no packaging designs have been defined so that values used were the best available estimates.

The distances of travel from each of the sources to each of the potential candidate sites were also determined. A simplifying assumption was made to reduce the number of spent fuel shipment origins from approximately 80 to a small number of centroids. Twenty-one reactor centroid locations were defined to replace the actual reactor locations. Distances were calculated using these centroids, but the distances from the actual locations of the other shipment origins were used. Table 1 identifies the total number of waste shipments required if all shipments were made by truck and all were made by rail. Table 2 contains the total one-way distance traveled for each scenario for each type of waste.

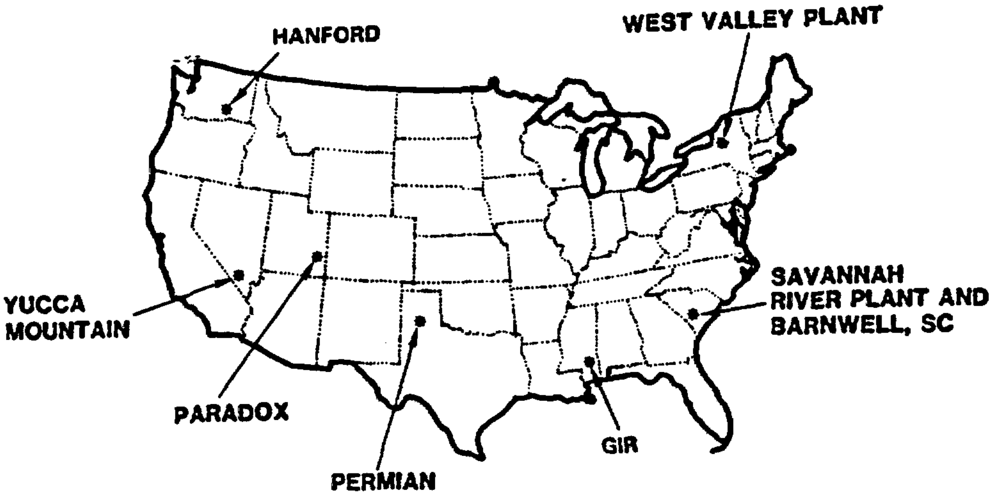

Figure 1. Five Potential Candidate Repository Sites

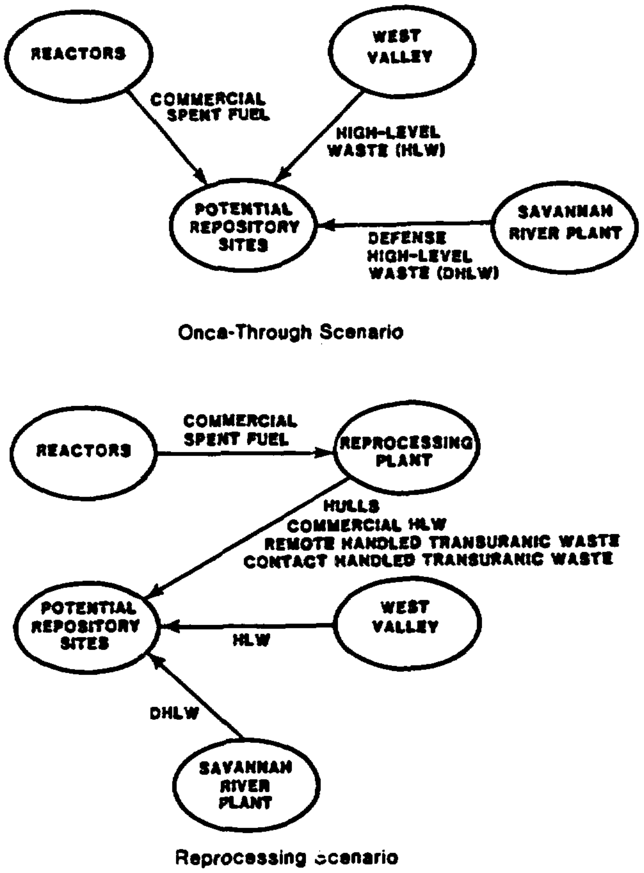

Figure 2. Schematics of Origins and Destinations of the Two Scenarios

Table 1. Number of Shipments Required for 26-yr Repository Operation (reprocessing and once-through)

Waste Type	100% Shipments by Rail	100% Shipments by Truck
Spent Fuel	13415	82469
DHLW	1344	6720
WVHLW	43	300
Reprocessing Waste (Reprocessing Only)		
CHLW	2632	31581
Hulls	2707	10826
RHTRU Waste	13536	54141
CHTRU Waste	7288	23684

Table 2. Total Distances of Shipment for 26-yr Period (million kilometers)*

	Spent Fuel	CHLW	Hulls	RHTRU Waste	CHTRU Waste	DHLW	WVHLW	Total
Once-Through Fuel Cycle								
Truck								
GIR	130	0	0	0	0	6	0.5	140**
Permian	180	0	0	0	0	15	0.8	190
Paradox	220	0	0	0	0	21	0.9	250
Hanford	290	0	0	0	0	29	1	320
Yucca Mt	270	0	0	0	0	24	1	300
Rail								
GIR	26	0	0	0	0	2	0.1	28
Permian	32	0	0	0	0	3	0.1	35
Paradox	40	0	0	0	0	5	0.1	45
Hanford	51	0	0	0	0	6	0.2	58
Yucca Mt	49	0	0	0	0	6	0.2	55
Reprocessing Fuel Cycle								
Truck								
GIR	120	29	10	50	22	6	0.5	240
Permian	120	70	24	120	52	15	0.8	400
Paradox	120	100	35	170	76	21	0.9	530
Hanford	120	140	47	230	100	29	1	670
Yucca Mt	120	120	40	200	87	24	1	590
Rail								
GIR	23	3	3	17	9	2	0.1	58
Permian	23	7	7	34	18	3	0.1	93
Paradox	23	10	10	50	27	5	0.1	120
Hanford	23	12	13	64	35	6	0.2	150
Yucca Mt	23	12	12	62	33	6	0.2	150

*One-way shipping distances
**Columns may not total due to rounding to two significant figures

For each type of waste, the total cost of transport was defined as the sum of capital costs, maintenance costs, and shipping charges. The total shipping costs were calculated using a computer code designed at Oak Ridge National Laboratory. The results are shown in Table 3. The total costs in millions of 1981 dollars are given for each repository and for each scenario. The cost values in the table do not consider site specific requirements such as access roads and rail spurs that must be constructed. The shipping cost values were based on published tariffs where possible or conservative estimates when tariffs were not available.

In order to assess risks, two additional factors were defined: unit-risk factors and the percentage of travel in various population zones. The unit-risk factors are a measure of the risk of traveling a distance of one kilometer in a particular population zone. These factors were defined for both normal and accident conditions encountered during transport. In addition, they were generated for nonradiological and radiological risks. The nonradiological risks are the latent cancer fatalities from pollutants emitted during transport and the traumatic deaths and injuries suffered in traffic accidents. These risks would occur irrespective of the nature of the cargo. The radiological risks, however, are determined by the nature of the cargo and its packaging. People are exposed to low levels of radiation when a shipment passes, even if an accident does not occur. Should an accident occur, they may receive additional exposure. The nonradiological unit-risk factors were based on statistics compiled at a federal or state level for both truck and rail. The radiological factors were calculated using a computer code, RADTRAN II (Reference 1), which combines the myriad of input data to produce the unit-risk factors for normal and accident conditions of transport. The radiological input data used were as specific to waste type and its packaging as was currently possible. Data not available were assumed to be consistent with past studies, particularly Reference 2.

The percentage of travel in each of three population zones was a refinement required because the unit-risk factors were generally different, depending on the population zone for which they were calculated. The travel percentages were obtained by overlaying computer-generated-graphics of population densities onto a selection of typical routes to each of the potential repository sites.

Table 4 was generated by combining the unit-risk factors, percent travel in population zones, the number of shipments, and the distance per shipment. The total risks are given for each potential site. In the table, results are categorized by fuel-cycle scenario, by mode of transport, and for radiological and nonradiological risks. Though both the radiological and nonradiological risks are given in terms of fatalities, there is an important distinction between the type of fatality. The latent cancer fatalities associated with the radiological risks are a predicted number of fatalities that would occur after a delayed period subsequent to exposure. Furthermore, the values in the table include not only fatalities occurring during this generation but also during all subsequent generations (fatalities resulting from genetic effects transferred to future generations). These numbers have their basis in statistical projections. The nonradiological fatalities on the other hand are immediate and would result whenever if an equivalent number of shipments and distances were accumulated hauling any cargo (lumber, potatoes, or any item of general commerce). These results also show a clear relationship with distance. The greater the total distance traveled, the greater the total risk will be.

Table 3. Total Costs for 26-yr Period ($ million)

	Repository Location				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through Fuel Cycle					
100% Truck	780	990	1200	1400	1500
100% Rail	810	970	1100	1200	1200
Reprocessing Fuel Cycle					
100% Truck	1400	2000	2500	2800	3100
100% Rail	1800	2400	2700	3000	3100

Since the work presented here is preliminary the level of uncertainty in the results is of note. Consider cost first. Important parameters in the cost evaluation are the numbers of waste shipments, hence uncertainties here are most important. The RHTRU and CHTRU wastes, which make up part of the reprocessing waste stream, predominate in the reprocessing scenario. They can produce as high as 60% of the overall cost, yet the uncertainty in the amount of these wastes generated from a metric ton of spent fuel precludes making conclusions about their significance at this point. They must be considered as important and be identified as parameters needing refinement. Many of the other cost parameters are quite dependent upon the cask design capacity; however, cask designs are not finalized. Packaging design is in need of refinement. In comparing truck and rail modes, it is important that rates be negotiated for the large volumes of wastes being considered in this analysis. Values in Table 3 are limiting values which probably overpredict costs (in terms of 1981 dollars).

The uncertainties in the risk results are also greatly dependent upon the refinement of basic inputs such as the quantities of waste and the packagings used. However, the majority of the radiological risk results from the shipment stopping during transit to its destination, whether by truck or rail. The amount of time spent at stops, the number of people at the stops, and their distance from the cargo are all important to the risk. Values for these parameters for the rail mode are very uncertain and are in need of much better definition. The truck mode values are more certain but could still be better defined. The radiological risk results must also be considered as limiting values. The radiological risks from normal transport are greater than those expected from accidents. The nonradiological risk results have the least uncertainty associated with them, and the nonradiological risks from accidents are much greater than from normal transport. The values for nonradiological risk are probably closer to values that would actually occur than are the radiological risk values.

The magnitude of all the risk results must be placed in some perspective in order to assess their significance. The values in Table 4 are for 26 yr of repository operation. In that same period and using the same models and data as used in this analysis, 117 000 latent cancer fatalities resulting from natural background radiation would be predicted for the nation. About 65 000 people would die from truck accidents and 32 000 would die from train accidents.

This document is envisioned as the first step in an iterative process that will identify key parameters and redefine values for these parameters. The results presented here overpredict results in order to avoid surprises at a later date as the repository evaluation proceeds. These results should allow a decision to be made as to whether or not the costs and risks of transport to each of the five repositories are acceptable.

Table 4. Total Risks for 26-yr Period

	Repository Location				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through Fuel Cycle					
100% Truck					
Radiological (latent cancer fatalities)	6	8	10	12	13
Nonradiological (fatalities)	15	22	29	36	38
100% Rail					
Radiological (latent cancer fatalities)	13	16	20	25	26
Nonradiological (fatalities)	1.1	1.4	1.8	2.2	2.3
Reprocessing Fuel Cycle					
100% Truck					
Radiological (latent cancer fatalities)	7.7	11	13	14	16
Nonradiological (fatalities)	26	45	61	69	73
100% Rail					
Radiological (latent cancer fatalities)	17	24	31	35	36
Nonradiological (fatalities)	2.3	3.9	5.1	6.1	6.2

References

[1] J. M. Taylor and S. L. Daniel, *RADTRAN II: A Revised Computer Code to Analyze Transportation of Radioactive Material*, SAND80-1943 (Albuquerque, NM: Sandia National Laboratories, October 1982).

[2] US Nuclear Regulatory Commission, *Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes*, NUREG-0170 (December 1977).

A Preliminary Analysis of the Cost and Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites

Introduction

To support the nomination for site characterization, environmental assessments of five potential candidate commerical nuclear repository sites are being performed. The five sites, named after the regions (Yucca Mountain is actually a site, not a region) in which they are located, are: the Gulf Interior Region (GIR), the Permian Basin, the Paradox Basin, Yucca Mountain, and the Hanford reservation. Figure 1 shows their locations. One of the assessments required to determine their suitability is to evaluate costs and risks of transporting nuclear wastes to them from reactors and from a reprocessing site. This report documents a preliminary analysis of the costs and risks for each of the five regions that contain potential candidate sites.

Scenarios and Waste Volume Assumptions

Two shipping scenarios were evaluated: the once-through fuel cycle and the reprocessing fuel cycle. The first considered the transport of high level waste (HLW) from Savannah River Plant and West Valley Reprocessing Plant and 72000 metric tons (tonnes) of heavy metal (tHM) in spent fuel (SF) to each of the five potential sites. All of the high-level waste from the Savannah River Plant (DHLW) and some from the West Valley Reprocessing Plant (WVHLW) is defense-related. The remainder of waste from West Valley and all the spent fuel was generated by the commercial nuclear industry.

The second scenario examined the effect of reprocessing. This scenario also considered the HLW from Savannah River and West Valley, but the utilities were assumed to ship 72 000 tHM of spent fuel to a reprocessing plant at Barnwell, SC. The reprocessor in Barnwell was then assumed to ship high-level waste and other reprocessing wastes to each of the potential candidate repository sites. The amount of waste shipped was assumed to be that generated during the reprocessing of the 72 000 tHM of spent fuel.

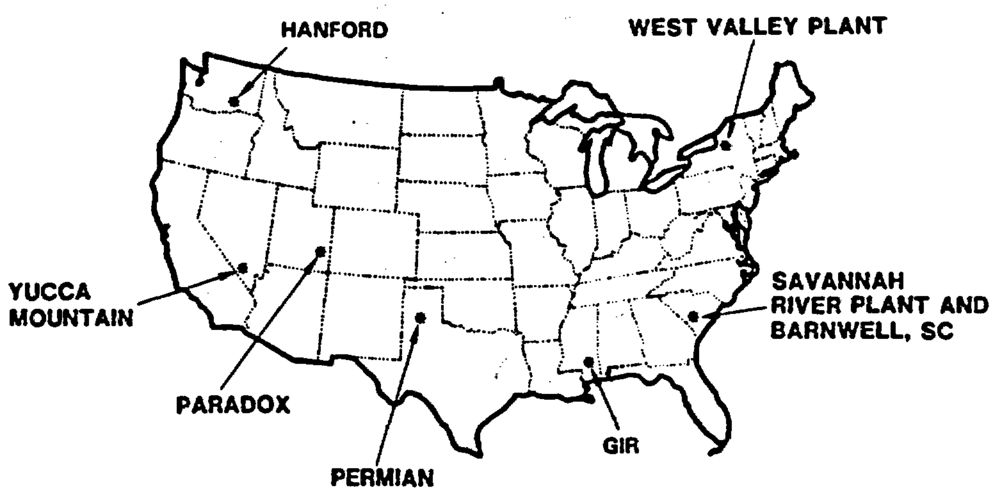

Figure 1. Five Potential Candidate Repository Sites

Each of the scenarios was evaluated for the case in which all shipments were made by truck and for the case in which all shipments were made by rail. Figure 2(a) is a schematic diagram showing the origins and destinations of the once-through scenario; Figure 2(b) is a schematic diagram of the reprocessing scenario. The waste types associated with each source are shown beside the arrows.

The repository is assumed to operate for 26 yrs. The total repository capacity was assumed to be 72 000 tHM of spent fuel assemblies (or the equivalent amount of reprocessing wastes), 6720 canisters of DHLW, and 300 canisters of WVHLW. The reprocessing of spent fuel assemblies will produce a number of waste streams that must be transported to a repository for final disposal: commercial high-level waste (CHLW), cladding hulls (hulls), remote handled transuranic (RHTRU) waste, and contact handled transuranic (CHTRU) waste. The repository receiving rates for the various wastes are shown in Table 1. A separate rate is included for each waste type along with the total number of containers produced over the 26-yr period. The conversion factors and container sizes used to calculate the amount of waste in each container are itemized in Table 2.

All radioactive wastes must be shipped in specially designed containers to ensure safe transport. The spent fuel, high-level wastes, RHTRU wastes, and hulls are assumed to be shipped in casks while the CHTRU wastes are assumed to be packaged in 55-gal drums that are placed in a specially designed overpack. The capacity shown for rail shipments of CHTRU waste represent two overpacks being carried on a single flat car. For truck shipments a single overpack is carried on a trailer.

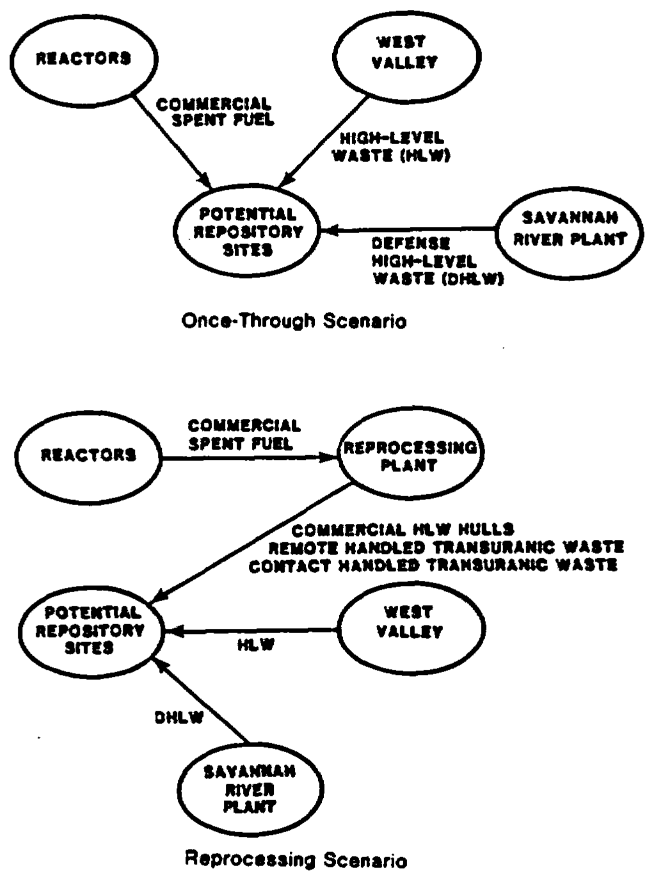

Figure 2. Schematics of Origins and Destinations of the Two Scenarios

Table 1. Repository Receiving Rates

	Years			
	1–5	6–14	15–26	Total
Once-Through:				
SF tHM/yr	1800	3000	3000	72 000
DHLW canister/yr	440	500	20	6720
WVHLW canister/yr	60	—	—	300
Reprocessing:				
CHLW canister/yr	789	1316	1316	31 581
Hulls canister/yr	271	451	451	10 826
RHTRU canister/yr	1353	2256	2256	54 141
CHTRU drums/yr	9474	15 789	15 789	378 939
DHLW canister/yr	440	500	20	6720
WVHLW canister/yr	60	—	—	300

Table 2. Reference Conversion Factors and Container Dimensions

Waste	Container	Reference Size	Conversion Factor (container/tHM)	Containers/Package Truck	Rail
SF	Assemblies	(PWR/BWR)* **		2/5	12/32
CHLW	Canister	0.32 x 3.0 m (12.75 x 120 in)	0.44	1	12
Hulls	Canister	0.76 x 3.0 m (30 x 120 in)	0.15	1	4
RHTRU	Canister	0.76 x 3.0 m (30 x 120 in)	0.75	1	4
CHTRU	Drum	207 l (55 gal)	5.26	16	52
DHLW	Canister	0.60 x 3.0 m (24 x 118 in)	NA	1	5
WVHLW	Canister	0.60 x 3.0 m (24 x 118 in)	NA	1	7

*Pressurized-Water-Reactor/Boiling-Water-Reactor
**Only the radiological characteristics of PWR spent fuel are used in the risk assessment.

Transportation Routing and Distances

While all spent fuel transportation parameters were determined on a reactor-by-reactor basis, detailed truck and rail routes were not generated from each individual reactor site. A number of reactor centroids were defined and reported transportation distances were calculated from the centroids to the appropriate destinations. All of the reactors in a particular National Electric Reliability Council (NERC) region were identified. The NERC region was then divided into subregions based upon the geographic location of the reactors. Once the reactors in a particular subregion were identified, the geographic centroid was calculated from the latitude and longitude of each unit within the subregion. The nearest node in the routing models to this calculated point that was included in both the routing model data bases was selected as the centroid for routing shipments. Actual source locations are used for the other waste types.

The one-way distances between the regional centroids (identified by the state in which the centroid is located) and the repository and reprocessing locations are shown in Tables 3 and 4. Estimated total distances used for the analyses are tabulated by the highway and rail routing models HIGHWAY[1] and INTERLINE[2], respectively.

Table 3. Estimated Highway Distances*

	Repository Site					Reprocessing Site
Origin	GIR km(mi)	Permian km(mi)	Paradox km(mi)	Yucca Mt km(mi)	Hanford km(mi)	Barnwell km(mi)
Reactor Centroid						
State						
IN	1001(622)	1772(1101)	2538(1577)	3228(2006)	3574(2221)	977(607)
OH	1469(913)	2166(1346)	2876(1787)	3566(2216)	3727(2316)	1003(623)
MI	1584(484)	2076(1290)	2625(1631)	3315(2060)	3476(2160)	1444(897)
TX	896(557)	869(540)	1823(1133)	2316(1439)	3289(2044)	1642(1020)
NJ	1809(1124)	2760(1715)	3510(2181)	4200(2610)	4408(2739)	1123(698)
NY	2007(1247)	2895(1799)	3544(2202)	4234(2631)	4395(2731)	1382(859)
MA	2234(1388)	3177(1974)	3854(2395)	4706(2824)	4545(2924)	1551(964)
MN	1783(1108)	1683(1046)	2168(1347)	2858(1776)	2562(1592)	1996(1240)
IA	928(806)	1157(719)	1635(1016)	2326(1445)	2544(1581)	1886(1172)
IL	1302(809)	1687(1048)	2185(1358)	2876(1787)	3095(1923)	1524(947)
WI	1638(1018)	2049(1273)	2512(1561)	3203(1990)	2989(1857)	1677(1042)
TN	624(388)	1732(1076)	2713(1686)	3206(1992)	3748(2329)	612(380)
NC	1043(648)	2321(1442)	3302(2052)	3795(2358)	4329(2690)	248(154)
GA	716(445)	2039(1267)	3021(1877)	3513(2183)	4244(2637)	317(195)
FL	1091(678)	2575(1600)	3559(2210)	4049(2516)	4865(3023)	753(468)
VA	1461(908)	2586(1607)	3375(2097)	4060(2523)	4411(2741)	682(424)
LA	367(228)	1125(699)	2107(1309)	2599(1615)	3508(2180)	1127(700)
KS	1141(709)	790(491)	1529(950)	2264(1407)	2845(1768)	1662(1033)
Southern CA	2935(1824)	1547(961)	1064(661)	595(370)	1928(1198)	3695(2296)
Northern CA	3632(2257)	2213(1375)	1580(982)	970(603)	1188(738)	4352(2704)
WA	3948(2453)	2541(1579)	1521(976)	1608(999)	137(85)	4397(2732)
Reprocessing/Other						
Savannah River	892(554)	2176(1352)	3158(1962)	3645(2265)	4284(2662)	—
West Valley, NY	1806(1122)	2509(1559)	3158(1962)	3853(2394)	4009(2491)	—
Barnwell, SC	927(576)	2211(1374)	3193(1984)	3681(2287)	4319(2684)	—

*One-way distances; total distance traveled by reusable packaging is twice the value presented here.

Table 4. Estimated Rail Distances*

Origin	Repository Site GIR km(mi)	Repository Site Permian km(mi)	Repository Site Paradox km(mi)	Repository Site Yucca Mt km(mi)	Repository Site Hanford km(mi)	Reprocessing Site Barnwell km(mi)
Reactor Centroid						
State						
IN	1289(801)	2231(1386)	2638(1639)	3447(2142)	3788(2354)	1378(856)
OH	1608(999)	2182(1356)	2829(1758)	3769(2342)	3811(2368)	1608(999)
MI	1746(1085)	2182(1356)	2742(1704)	3570(2218)	3724(2314)	1643(1021)
TX	993(617)	1025(637)	2750(1709)	2926(1818)	4057(2521)	2120(1317)
NJ	2348(1465)	2953(1835)	3600(2237)	4519(2808)	4582(2847)	1136(706)
NY	2403(1493)	2869(1783)	3632(2257)	4464(2774)	4806(2986)	1524(947)
MA	2699(1677)	3317(2061)	3888(2416)	4859(3019)	4870(3026)	1872(1163)
MN	1899(1180)	2288(1422)	2182(1356)	2937(1825)	2657(1651)	2253(1400)
IA	1693(1052)	1259(782)	1535(954)	2412(1499)	2678(1726)	2166(1346)
IL	1487(924)	1548(96[illegible])	2111(1312)	2989(1857)	3233(2009)	1772(1101)
WI	1555(966)	2052(1275)	2472(1536)	3304(2053)	3645(2265)	1909(1186)
TN	1057(657)	2540(1578)	2828(1757)	3636(2259)	2977(2471)	771(479)
NC	1184(736)	2562(1592)	3618(2248)	4426(2750)	4769(2962)	364(226)
GA	745(463)	2345(1457)	3446(2141)	4253(2643)	4595(2855)	391(243)
FL	1225(761)	2931(1821)	4134(2569)	4942(3071)	5283(3283)	834(518)
VA	1524(947)	2873(1785)	3906(2427)	4714(2929)	5055(3141)	676(420)
LA	414(257)	1415(879)	2672(1660)	3639(2261)	3980(2473)	1828(1136)
KS	1226(762)	872(542)	1859(1155)	2826(1756)	3167(1968)	2023(1257)
Southern CA	3520(2187)	1746(1085)	2435(1513)	571(355)	2364(1469)	4347(2701)
Northern CA	4421(2747)	2647(1645)	1592(989)	1138(707)	1521(945)	5248(3261)
WA	4459(2771)	3272(2033)	1769(1099)	2081(1293)	192(119)	4960(3082)
Reprocessing/Other						
Savannah River	1250(777)	2544(1581)	3710(2305)	4575(2843)	4749(2951)	—
West Valley, NY	2327(1446)	2712(1685)	3372(2095)	4303(2674)	4300(2672)	—
Barnwell, SC	1250(777)	2544(1581)	3710(2305)	4575(2843)	4749(2951)	—

*One-way distances; total distance traveled by reusable packaging is twice the value presented here.

The HIGHWAY model is designed to simulate routes on the highway system in the US. The data base includes all interstates, most US highways, and many roadways with state, county, or local classifications. It represents approximately 240 000 miles of roadway. Several different routing options are available in the highway program, including probable commercial routes, routes on the interstate system, and routes that bypass major urbanized areas. Additional detailed routing analyses can be performed by blocking individual or sets of highway segments or intersections contained in the data base. In calculating possible routes for this analysis, routes normally used for general commerce were estimated. No specific constraints of any state or local restrictions applying to the shipment of radioactive materials were included in the routing criteria.

The INTERLINE model is designed to simulate routing on the railroad system. Originally compiled in 1974 by the Federal Railroad Administration, the rail data base has been extensively reworked to reflect rail company mergers and line abandonments. The railroad network is separated into 95 separate subnetworks to replicate actual routing practices of the individual railroad companies. As with the truck routing model, railway lines, intersections, or transfer points can be blocked to permit analysis of track closures or routing restrictions. The INTERLINE model has many of the routing capabilities of the HIGHWAY model. Routes can be estimated that bypass specific geographic areas or specific railroad systems. No specific routing constraints were imposed in this analysis. All rail shipments were assumed to travel as general freight between the origin and destination.

Transportation Logistics Methods/Assumptions

Transportion requirements and shipment numbers were calculated by a computer code designed for that purpose at the Oak Ridge National Laboratory. Based upon the waste quantities requiring shipment and the reference transportation packaging descriptions, a total waste flow (or number of shipments required) was tabulated for both truck and rail. The number of shipments of spent reactor fuel are based upon the use of the DOE Spent Fuel Data Base. The projected spent fuel storage requirements were based on the following assumptions:

1. The spent fuel discharge data published in Reference 3.
2. Full-core reserve at each reactor storage pool.
3. Maximum expansion of reactor storage pools.
4. Planned transshipments of spent fuel, as identified in Reference 3, will take place.
5. Reactors will be decommissioned at the end of their commercial life by shipping all remaining fuel assemblies over a 5-yr period.
6. Spent fuel assemblies, stored at West Valley and Morris, will ship inventories between years 4 through 13 as described in Table 1.

The annual shipping schedule is a function of transportation mode since all shipping casks are assumed to be fully loaded. The total number of shipments identified for the reactors associated with a particular reactor centroid are shown in Table 5.

Transportation Costs

Transportation costs for each waste type identified are defined as the sum of the following three costs:

- Capital
- Maintenance
- Shipping

Costs used in this analysis are based upon 1981 dollars and should be used only for comparisons between sites.

The total transportation costs for each fuel-cycle scenario (once-through or reprocessing) are then the sum of the transportation costs for each waste type to any of the potential repository locations. Transportation costs depend directly upon the total quantity of waste requiring shipment which is distributed on a yearly basis between each origin-destination pair for the lifetime of a repository. This total flow is identified in Table 1. The total number of shipments were calculated by waste type, mode, and year by using the transportation package definitions of Table 2. This information, together with the average speeds, turnaround times, and availability of packagings, was then used to calculate a total transportation package requirement for each waste type. Similarly, the total number of shipments, mileage, and empty and loaded package weights are used to calculate shipping costs.

All truck shipments were assumed to travel at an average speed of 35 mph. The average rail speed varies from ~3 mph for short hauls to ~12 mph for cross-country shipments. In addition to the transit time, additional time is added for loading the casks at the waste generator and unloading the casks at a repository. For shipments, a total loading plus unloading time was assumed to be 5 days for a rail package, and 3 days for a truck package. Transport packages were assumed to be available 300 days per year.

Table 5. Number of Shipments Required (reprocessing and once-through)

Waste Type	100% Shipments by Rail	100% Shipments by Truck
Spent Fuel		
IN	124	746
OH	547	3409
MI	770	4674
TX	365	2220
NJ	1545	9624
NY	792	4900
MA	1069	6542
MN	382	2341
IA	282	1777
IL	1838	11 431
WI	211	1281
TN	1027	6345
NC	1093	6644
GA	441	2712
FL	455	2727
VA	468	2825
LA	324	1997
KS	231	1451
Southern CA	636	3818
Northern CA	108	657
WA	707	4348
Total	13415	82469
DHLW	1344	6720
WVHLW	43	300
Reprocessing Waste		
CHLW	2632	31 581
Hulls	2707	10 826
RHTRU Waste	13 536	54 141
CHTRU Waste	7288	23 684

Capital Costs

Capital costs are defined as the cost of the transportation packaging and its trailer or railcar. Estimates are given in Table 6. They do not include fixed facility requirements such as highway or rail-line construction to the repository site, or facility handling-equipment requirements.

Transportation packagings were assumed to be licensed with an estimated lifetime of 15 yr. Hence, for each of the waste streams except DHLW and WVHLW, the packagings must be replaced once during the lifetime of the first repository.

Table 6. Transportation Package Capital Costs ($ x 10^6) (including trailer or railcar)

	Transportation Mode	
Waste Type	Truck	Rail
Spent Fuel	1.4	2.5
CHLW	1.1	1.8
Hulls	1.1	1.8
RHTRU	1.1	1.8
CHTRU	0.7	1.3
DHLW	1.1	1.8
WVHLW	1.1	1.8

For each waste type, the repository receiving rate was used to define the waste flow by type by year. For the DHLW, WVHLW, and each of the waste types from reprocessing to repository, this receipt rate was combined with the packaging characteristics to directly define the number of packagings required for each waste type for each year. The number of packagings required varies with the site chosen because of the variation in the distance (and hence travel time) for each site.

An exception to this method is the calculation of spent-fuel packagings required. Spent-fuel was assumed to arrive at the rate defined in Table 1. However, the computerized model bases the number of packagings required (by year) on the spent-fuel flows defined by the DOE Spent-Fuel Data Base, as discussed in the previous section. To determine the spent-fuel packaging requirements for the first repository, the total number of packaging-years identified by the model was divided by the total number of years of repository lifetime. The number of packagings thus identified was then doubled to calculate the total number of spent-fuel packagings required. Table 7 summarizes this method.

The total number of packagings required for each waste type is given in Table 8. The costs per packaging, times these packaging requirements, defines the total capital cost for each waste type, by site, as shown in Table 9. The total capital cost for the once-through fuel-cycle is the sum of the capital costs of spent fuel, DHLW, and WVHLW to the candidate site. The total capital cost for the reprocessing fuel cycle is the sum of costs of spent fuel to Barnwell, and the CHLW, hulls, RHTRU waste, CHTRU waste, DHLW, and WVHLW to the candidate site.

Maintenance Costs

The average number of packagings required per year was multiplied by a maintenance/licensing constant given in Table 10 to obtain the total maintenance cost by waste type shown in Table 11. Since this cost varies with the number of packagings required per year, each candidate site will have a different maintenance cost.

Table 7. Spent-Fuel Transportation Packaging Requirements

	Repository					Reprocessing
	GIR	Permian	Paradox	Yucca Mt	Hanford	Barnwell
Truck						
Total Package-yr	1485	1700	1893	2119	2184	1401
Avg Package	58	66	73	82	85	54
Total Package Requirements	116	132	146	164	170	108
Rail						
Total Package-yr	981	1104	1186	1279	1298	915
Avg Package	38	43	46	50	50	36
Total Package Requirements	76	86	92	100	100	72

Table 8. Total Transportation Packaging Requirements by Waste Type

Scenario/Mode/Waste Type	Repository				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through					
100% Truck					
SF	116	132	146	164	170
DHLW	8	11	13	14	16
WVHLW	2	2	2	2	2
100% Rail					
SF	76	86	92	100	100
DHLW	8	9	11	11	12
WVHLW	1	1	1	1	1
Reprocessing					
100% Truck					
SF to Barnwell	108	108	108	108	108
CHLW	40	56	64	76	84
Hulls	14	20	24	26	30
RHTRU	66	96	118	128	142
CHTRU	30	42	52	56	62
DHLW	8	11	13	14	16
WVHLW	2	2	2	2	2
100% Rail					
SF to Barnwell	72	72	72	72	72
CHLW	16	20	24	26	26
Hulls	18	20	24	26	26
RHTRU	82	100	118	124	126
CHTRU	44	54	64	68	68
DHLW	8	9	11	11	12
WVHLW	1	1	1	1	1

Table 9. Capital Costs by Waste Type ($ x 10^8)

Scenario/Mode/Waste Type	Repository GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through:					
100% Truck					
SF	1.62	1.85	2.04	2.30	2.38
DHLW	0.09	0.12	0.14	0.15	0.18
WVHLW	0.02	0.02	0.02	0.02	0.02
Total	1.73	1.99	2.20	2.47	2.58
100% Rail					
SF	1.90	2.15	2.30	2.50	2.50
DHLW	0.14	0.16	0.20	0.20	0.22
WVHLW	0.02	0.02	0.02	0.02	0.02
Total	2.06	2.33	2.52	2.72	2.74
Reprocessing:					
100% Truck					
SF to Barnwell	1.51	1.51	1.51	1.51	1.51
CHLW	0.44	0.62	0.70	0.84	0.92
Hulls	0.15	0.22	0.26	0.29	0.33
RHTRU	0.73	1.06	1.30	1.41	1.56
CHTRU	0.21	0.29	0.36	0.39	0.43
DHLW	0.09	0.12	0.14	0.15	0.18
WVHLW	0.02	0.02	0.02	0.02	0.02
Total	3.15	3.84	4.29	4.61	4.95
100% Rail					
SF to Barnwell	1.80	1.80	1.80	1.80	1.80
CHLW	0.29	0.36	0.43	0.47	0.47
Hulls	0.32	0.36	0.43	0.47	0.47
RHTRU	1.48	1.80	2.12	2.23	2.27
CHTRU	0.57	0.70	0.83	0.88	0.88
DHLW	0.14	0.16	0.20	0.20	0.22
WVHLW	0.02	0.02	0.02	0.02	0.02
Total	4.62	5.20	5.83	6.07	6.13

Table 10. Transportation Package Maintenance Costs per Year ($$10^6$/package-yr)

Waste Type	Transportation Mode Truck	Rail
Spent Fuel	0.075	0.125
CHLW	0.06	0.09
Hulls	0.06	0.09
RHTRU	0.06	0.09
CHTRU	0.075	0.125
DHLW	0.06	0.09
WVHLW	0.06	0.09

Table 11 gives the total maintenance cost by waste type, mode, and candidate site. As with the total capital cost for each scenario, the once-through fuel-cycle transportation maintenance cost was calculated by adding spent fuel, DHLW, and WVHLW costs to each candidate site. The reprocessing fuel-cycle transportation maintenance cost is obtained by adding the costs for spent fuel to Barnwell plus the reprocessing waste streams and DHLW and WVHLW to each site.

Table 11. Maintenance Costs by Waste Type for 26-yr Period ($)

Scenario/Mode/Waste Type	Repository GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through					
100% Truck					
SF	1.04×10^8	1.19×10^8	1.31×10^8	1.48×10^8	1.53×10^8
DHLW	0.06×10^8	0.09×10^8	0.10×10^8	0.11×10^8	0.13×10^8
WVHLW	0.06×10^7	0.06×10^7	0.06×10^7	0.06×10^7	0.06×10^7
Total	1.11×10^8	1.29×10^8	1.42×10^8	1.60×10^8	1.67×10^8
100% Rail					
SF	1.14×10^8	1.29×10^8	1.38×10^8	1.50×10^8	1.50×10^8
DHLW	0.10×10^8	0.11×10^8	0.13×10^8	0.13×10^8	0.15×10^8
WVHLW	0.04×10^7	0.04×10^7	0.04×10^7	0.04×10^7	0.04×10^7
Total	1.24×10^8	1.40×10^8	1.51×10^8	1.63×10^8	1.65×10^8
Reprocessing					
100% Truck					
SF to Barnwell	0.97×10^8	0.97×10^8	0.97×10^8	0.97×10^8	0.97×10^8
CHLW	0.29×10^8	0.40×10^8	0.49×10^8	0.55×10^8	0.60×10^8
Hulls	0.10×10^8	0.14×10^8	0.17×10^8	0.19×10^8	0.22×10^8
RHTRU	0.48×10^8	0.69×10^8	0.85×10^8	0.92×10^8	1.02×10^8
CHTRU	0.27×10^8	0.38×10^8	0.47×10^8	0.50×10^8	0.56×10^8
DHLW	0.60×10^8	0.09×10^8	0.10×10^8	0.11×10^8	0.13×10^8
WVHLW	0.06×10^7	0.06×10^7	0.06×10^7	0.06×10^7	0.06×10^7
Total	2.18×10^8	2.68×10^8	3.06×10^8	3.25×10^8	3.51×10^8
100% Rail					
SF to Barnwell	1.08×10^8	1.08×10^8	1.08×10^8	1.08×10^8	1.08×10^8
CHLW	0.17×10^8	0.22×10^8	0.26×10^8	0.28×10^8	0.28×10^8
Hulls	0.19×10^8	0.22×10^8	0.26×10^8	0.28×10^8	0.28×10^8
RHTRU	0.89×10^8	1.08×10^8	1.27×10^8	1.34×10^8	1.36×10^8
CHTRU	1.32×10^8	1.62×10^8	1.92×10^8	2.04×10^8	2.04×10^8
DHLW	0.10×10^8	0.11×10^8	0.13×10^8	0.13×10^8	0.15×10^8
WVHLW	0.04×10^7	0.04×10^7	0.04×10^7	0.04×10^7	0.04×10^7
Total	3.75×10^8	4.33×10^8	4.92×10^8	5.15×10^8	5.19×10^8

Shipping Costs

Shipping costs were determined for the given waste types and calculated shipment distances. The shipping rates used for this analysis were based upon either (1) studies of published tariffs, or (2) conservative estimates. For this analysis, July 1981 tariffs for truck and rail were used. Actual shipping rates were determined through negotiation between the shipper's traffic management organization and the carrier. Actual costs depend on departure and arrival constraints, wait times, regulatory, accounting, or notification requirements, and other factors affecting the operating characteristics of the vehicles.

The loaded and empty packaging weights used for this analysis are summarized in Table 12.

The model (based upon these weights, on the input tariff studies, and on shipment distances) used a cost correlation equation to calculate the shipping costs. Table 13 summarizes these costs by waste type and shipment destination. Total shipping costs for each of the scenarios were calculated as previously discussed.

Summary of Total Transportation Costs for the Two Fuel-Cycle Scenarios By Major Cost Category

Once-Through Fuel-Cycle

Table 14 details the total transportation related costs for the once-through fuel-cycle scenario by major cost category (capital, maintenance, and shipping costs). This table shows the influence of distance upon total transportation cost for either mode of travel (truck or rail); total cost is least for the easternmost site (GIR) and greatest for the most western site (Hanford). Shipping costs for truck appear to vary almost linearly with the total site shipping distances; costs for rail are somewhat less on a weight-per-distance basis.

Table 12. Summary of Loaded and Empty Packaging Weights Used in Analysis of Shipping Costs (average packaging weights)

	Truck				Rail			
	Loaded		Empty		Loaded		Empty	
	kg	(lb)	kg	(lb)	kg	(lb)	kg	(lb)
SF	22 200	(49 000)	21 200	(46 700)	90 700	(200 000)	81 600	(180 000)
CHLW	22 300	(49 200)	21 400	(47 300)	80 300	(177 000)	70 000	(154 400)
Hulls	22 700	(50 000)	17 700	(39 000)	90 700	(200 000)	70 800	(156 000)
RHTRU	22 700	(50 000)	18 100	(40 000)	90 700	(200 000)	72 600	(160 000)
CHTRU	22 700	(50 000)	13 600	(32 000)	63 500	(140 000)	36 300	(80 000)
DHLW	22 700	(50 000)	20 600	(45 490)	90 700	(200 000)	80 500	(177 450)
WVHLW	22 700	(50 000)	20 600	(45 490)	90 700	(200 000)	75 000	(165 350)

Table 13. Total Shipping Costs for 26-yr Period ($)

	Repository				
Scenario/Mode/Waste Type	GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through					
100% Truck					
SF	4.67×10^8	6.08×10^8	7.35×10^8	8.94×10^8	9.41×10^8
DHLW	0.23×10^8	0.51×10^8	0.74×10^8	0.86×10^8	1.00×10^8
WVHLW	0.02×10^8	0.03×10^8	0.03×10^8	0.04×10^8	0.04×10^8
Total	4.92×10^8	6.62×10^8	8.12×10^8	9.84×10^8	1.04×10^9
100% Rail					
SF	4.48×10^8	5.37×10^8	6.08×10^8	6.93×10^8	7.16×10^8
DHLW	0.34×10^8	0.56×10^8	0.70×10^8	0.84×10^8	0.87×10^8
WVHLW	0.02×10^8	0.02×10^8	0.02×10^8	0.02×10^8	0.02×10^8
Total	4.84×10^8	5.95×10^8	6.80×10^8	7.79×10^8	8.05×10^8
Reprocessing					
100% Truck					
SF to Barnwell	4.18×10^8	4.18×10^8	4.18×10^8	4.18×10^8	4.18×10^8
CHLW	1.14×10^8	2.45×10^8	3.54×10^8	4.08×10^8	4.79×10^8
Hulls	0.37×10^8	0.80×10^8	1.15×10^8	1.33×10^8	1.56×10^8
RHTRU	1.88×10^8	4.02×10^8	5.80×10^8	6.69×10^8	7.85×10^8
CHTRU	0.78×10^8	1.66×10^8	2.39×10^8	2.75×10^8	3.23×10^8
DHLW	0.23×10^8	0.51×10^8	0.74×10^8	0.86×10^8	1.00×10^8
WVHLW	0.02×10^8	0.03×10^8	0.03×10^8	0.04×10^8	0.04×10^8
Total	8.60×10^8	1.36×10^9	1.78×10^9	1.99×10^9	2.26×10^9
100% Rail					
SF to Barnwell	4.11×10^8	4.11×10^8	4.11×10^8	4.11×10^8	4.11×10^8
CHLW	0.59×10^8	0.97×10^8	1.21×10^8	1.47×10^8	1.51×10^8
Hulls	0.64×10^8	1.07×10^8	1.33×10^8	1.62×10^8	1.66×10^8
RHTRU	3.26×10^8	5.39×10^8	6.72×10^8	8.17×10^8	8.41×10^8
CHTRU	1.18×10^8	1.92×10^8	2.38×10^8	2.88×10^8	2.96×10^8
DHLW	0.34×10^8	0.56×10^8	0.70×10^8	0.84×10^8	0.87×10^8
WVHLW	0.02×10^8	0.02×10^8	0.02×10^8	0.02×10^8	0.02×10^8
Total	1.01×10^9	1.40×10^9	1.65×10^9	1.91×10^9	1.95×10^9

Table 14. Transportation Cost Summary by Major Cost Category — Once-Through for 26-yr Period ($)

Mode/Cost Category	Repository GIR	Permian	Paradox	Yucca Mt	Hanford
100% Truck					
Capital	1.73×10^8	1.99×10^8	2.20×10^8	2.47×10^8	2.58×10^8
Maintenance	1.11×10^8	1.29×10^8	1.42×10^8	1.60×10^8	1.67×10^8
Shipping	4.92×10^8	6.62×10^8	8.12×10^8	9.84×10^8	1.04×10^9
Total	7.76×10^8	9.90×10^8	1.17×10^9	1.39×10^9	1.46×10^9
100% Rail					
Capital	2.06×10^8	2.33×10^8	2.52×10^8	2.72×10^8	2.74×10^8
Maintenance	1.24×10^8	1.40×10^8	1.51×10^8	1.63×10^8	1.65×10^8
Shipping	4.84×10^8	5.95×10^8	6.80×10^8	7.79×10^8	8.05×10^8
Total	8.14×10^8	9.68×10^8	1.08×10^9	1.21×10^9	1.24×10^9

Truck total costs are less than rail only for the GIR. However, as previously indicated, these totals were based upon published tariffs rather than negotiated rates. The capital and maintenance costs are less for truck for most sites, but the truck mode experiences a consistently greater shipping cost for each site. Shipping costs comprise 63% to 73% of the total transportation costs for truck and 59% to 65% of the total for rail. In both cases, the percentage increases with the total trip distance.

Reprocessing Fuel Cycle

Table 15 details the total transportation costs for each of the sites for the reprocessing scenario. For this scenario, both truck and rail total costs increase more rapidly than the distance; truck transportation costs are less than rail costs for all but the Hanford site. Shipping costs again are the dominant factor, comprising 61% to 72% of the truck cost totals and 55% to 63% of the rail cost totals. As before, the percentage varies with the total shipping distances to the sites.

Table 15. Transportation Cost Summary by Major Cost Category — Reprocessing for 26-yr Period ($)

Mode/Cost Category	Repository GIR	Permian	Paradox	Yucca Mt	Hanford
100% Truck					
Capital	3.15×10^8	3.84×10^8	4.29×10^8	4.61×10^8	4.95×10^8
Maintenance	2.18×10^8	2.68×10^8	3.06×10^8	3.25×10^8	3.51×10^8
Shipping	8.60×10^8	1.36×10^9	1.78×10^9	1.99×10^9	2.26×10^9
Total	1.39×10^9	2.01×10^9	2.52×10^9	2.78×10^9	3.11×10^9
100% Rail					
Capital	4.62×10^8	5.20×10^8	5.83×10^8	6.07×10^8	6.13×10^8
Maintenance	3.75×10^8	4.33×10^8	4.92×10^8	5.15×10^8	5.19×10^8
Shipping	1.01×10^9	1.40×10^9	1.65×10^9	1.91×10^9	1.95×10^9
Total	1.85×10^9	2.35×10^9	2.72×10^9	3.03×10^9	3.08×10^9

Summary of Total Transportation Costs

Table 16 summarizes the total transportation costs for each of the two fuel-cycle scenarios by transportation mode. Direct comparison between the once-through and reprocessing fuel cycles should be avoided because of the dependence of the reprocessing costs on the assumptions regarding (1) waste generation amounts, (2) conditions for transport, and (3) waste-form characteristics.

Details of the transportation equipment requirements, shipment distances, and shipping costs are given by site in Appendix A. Examination of these tables illustrates the relatively large impact of the generation amounts of RHTRU and CHTRU wastes per tHM of spent fuel being reprocessed.

Risk Analysis

In evaluating the overall risk for each scenario, a number of component risks must be evaluated. Two components immediately become obvious: the risk associated with accidents and the risk associated with transport when the shipment proceeds without incident (normal transport). Each of these components can be evaluated by considering the radiological characteristics of the load (radiological risk) and by considering those risks that result regardless of the radiological characteristics of the load (nonradiological risk). The normal transport component for radiological risk considers the direct external radiation dose emitted by the radioactive material package as the shipment passes by. The accident component for radiological risk considers the release of material from a package and the resultant impact. The health effects from the pollutants generated by burning diesel fuel to move the shipment is the measure of the nonradiological effects for normal transport. Traumatic deaths from traffic accidents are evaluated as the measure for nonradiological effects of accidents. The nonradiological effects would be generated irrespective of the radiological nature of the load.

A further subcategorization of risk can be made according to the population groups affected. For this analysis, a distinction was made between people exposed as a result of their occupation and those exposed on a random basis. Persons such as crew members of trains and truck drivers are considered to be occupationally exposed. The public is the nonoccupationally exposed group. When assessing some risks, it is difficult to separate occupationally exposed persons from those nonoccupationally exposed. As a result, a separate value for occupationally exposed people is not always available.

An important distinction must be made between the health effects resulting from accidents and calculated for radiological and nonradiological aspects of the total risk. The health effects for nonradiological impacts of accidents are calculated in terms of immediate, traumatic deaths; the health effects for radiological impacts of accidents are calculated in terms of latent cancer fatalities (deaths resulting several years later).

All results from accidents involving a radioactive material release are given in terms of expected fatalities since the basic definition of risk is the product of the consequence of an event times the likelihood of its occurrence. Consequences for a number of different severity accidents are evaluated and then multiplied by their respective probability of occurrence. The product is the risk from radiological accidents and represents the expected number of latent fatalities for the lifetime of the repository.

Table 16. Summary of Total Transportation Costs for the Two Fuel-Cycle Scenarios by Mode of Transportation for 26-yr Period ($)

Scenario/Mode	Repository: GIR	Permian	Paradox	Yucca Mt	Hanford
Once-Through					
100% Truck	7.8×10^8	9.9×10^8	1.2×10^9	1.4×10^9	1.5×10^9
100% Rail	8.1×10^8	9.7×10^8	1.1×10^9	1.2×10^9	1.2×10^9
Reprocessing					
100% Truck	1.4×10^9	2.0×10^9	2.5×10^9	2.8×10^9	3.1×10^9
100% Rail	1.8×10^9	2.4×10^9	2.7×10^9	3.0×10^9	3.1×10^9

Methods

The approach used in this evaluation was to calculate unit factors for all the radiological and nonradiological risks. Unit factors used for estimating the environmental impacts of transporting nuclear materials are increments of risk for a unit of distance traveled. These unit factors were calculated for each of three population zones: urban, suburban, and rural.

Once the unit factors were calculated, they were combined with three other terms: the number of shipments for each shipping scenario, the distance per shipment, and the fraction of travel in various population zones. The products were summed according to the following formula to obtain the risk for each scenario. The remainder of this section describes the methods for calculating the unit factors for the radiological and nonradiological risks, as well as the methods used to develop the values for the other parameters.

$$\sum_{i} = \text{Pop Zone} \quad \sum_{j} = \text{Waste Type} \quad \sum_{k} = \text{Unit Factors} \quad \left[\begin{array}{l} (\text{Unit factors})_{ij,k} \\ \times\ (\text{number of shipments})_{j} \\ \times\ (\text{miles per shipment})_{j} \\ \times\ (\%\ \text{travel in population zones})_{ij} \end{array} \right] = \text{Total Impact}$$

Radiological Unit Factors

This analysis uses a simplified technique for calculating the risk components. Unit factors are calculated that represent the risk per unit distance of travel. The factors must be evaluated for each risk component discussed. In addition, the total distance of shipment for each scenario must be calculated. The product of a unit-factor and the total distance is the total risk for that component. If the total risk for each component is added, then the risk for a scenario is obtained.

The radiological unit factors were calculated using a computer code, RADTRAN II, which combines the large set of parameters necessary to calculate radiological impacts. RADTRAN II has been documented previously in Reference 4, but its models will be discussed briefly here.

Even if no accidents occur during shipment, low levels of radiation expose crew members and the population surrounding the route (refer to Figure 3). For some population subgroups, the exposure is received while the shipment is moving and, for others, while it is stationary. However, point-source geometry is the basis for most subgroup models included in this assessment. Derivations of all equations are discussed in Reference 4.

The normal impacts to the occupationally exposed population are calculated by the crew model. Numbers of crewmen, distances to the crew compartment, transport index (exposure rate term defined by regulations), package dimension, and velocity are required input for the truck-mode. Because of the large amounts of shielding and the large source-to-crew distances, the rail crew doses are not considered in the model. However, Department of Transportation regulations require that railcars carrying hazardous material be inspected at interchanges. Therefore, the dose to an inspector is modeled.

The normal impacts to the nonoccupationally exposed group are calculated by combining impacts to people at places where a shipment stops, to persons in vehicles sharing the transport link with a shipment, and persons within 800 m surrounding the transport link while a shipment is moving. Impacts to both pedestrians and persons in buildings are formulated in the off-link models. Average number of persons and their distances from the shipment are included in the stops model.

Impacts from accidents can result from abnormal transport occurrences in which material is released from a package or the package shielding is lost (refer to Figure 4). The probability that an accident releasing radioactive material will occur is formulated in terms of the expected number of accidents in each of eight severity categories. Package response and, hence, release or loss of shielding is related to the severity class for each type of package used. Health effects caused by the release of radionuclides to the environment are evaluated for several pathways: groundshine, cloudshine, and inhalation. The ingestion pathway is not considered since it is assumed that federal, state, or local authorities would intervene by impounding crops and cleaning up contaminated land. Released material is assumed to be dispersed according to Gaussian diffusion models, which predict downwind airborne concentrations and ground deposition. Airborne concentrations are converted to expected organ doses by standard dosimetric conversion factors. An infinite plane source model is used to analyze external exposure from ground contamination.

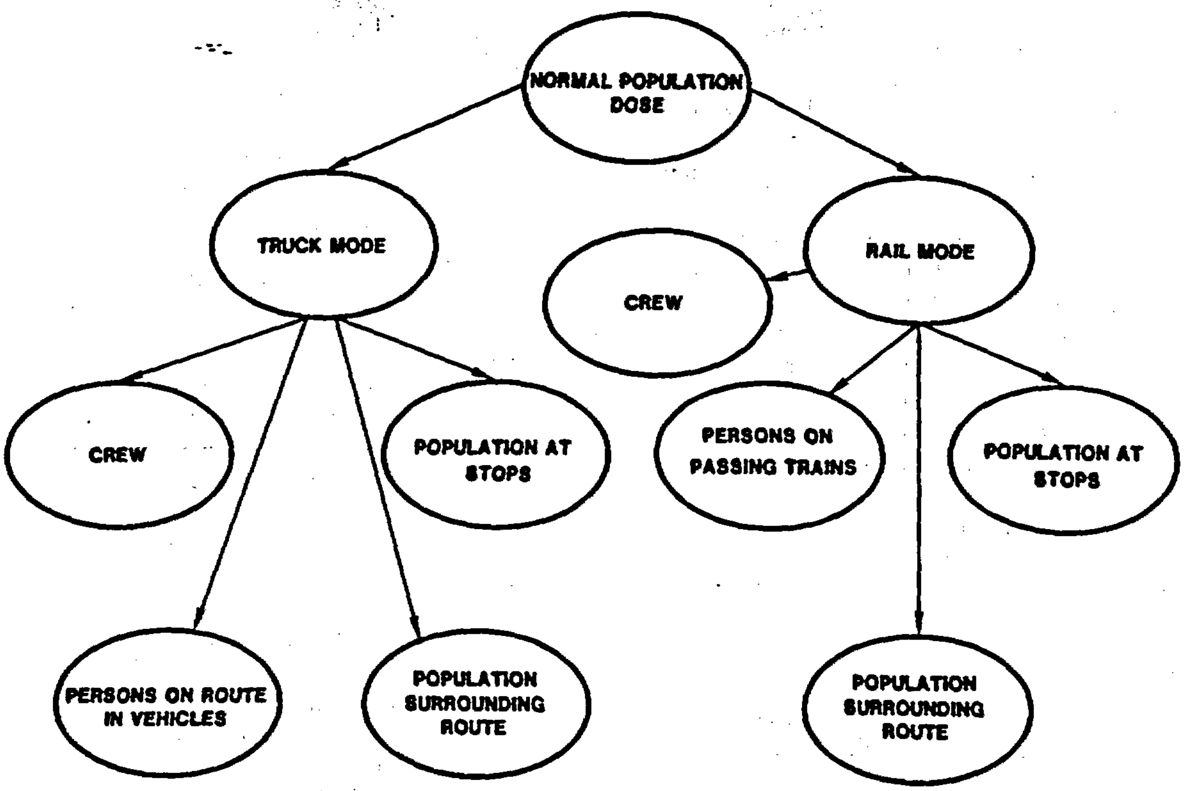

Figure 3. Normal Population Dose Models

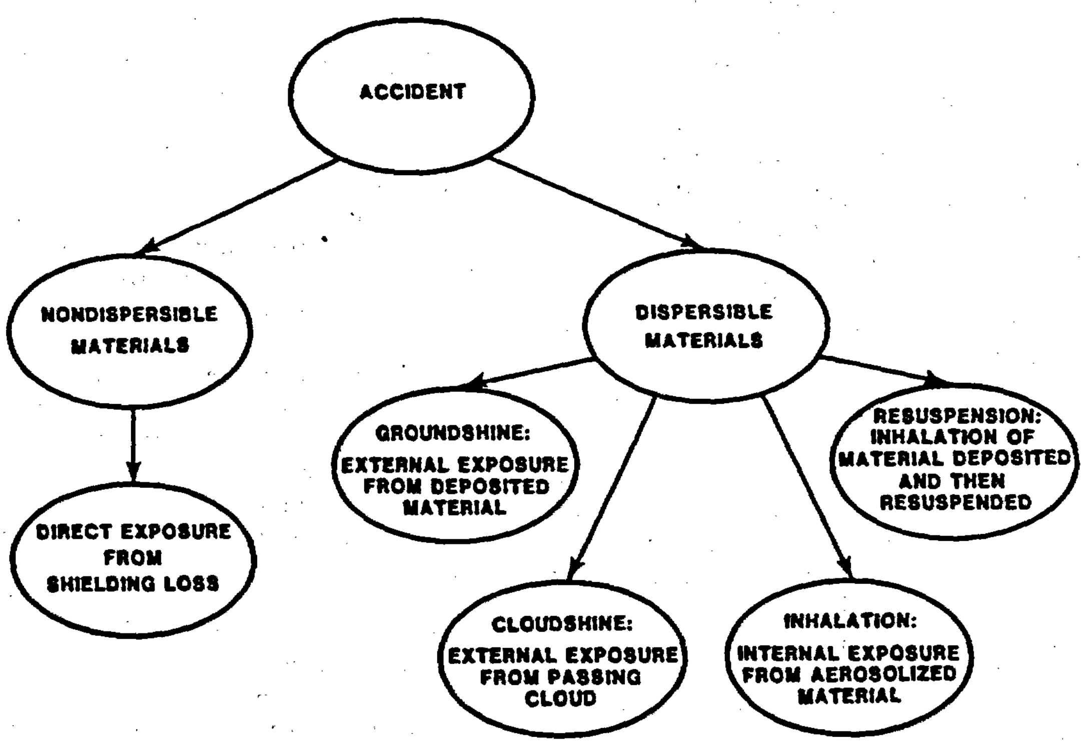

Figure 4. Accident Dose Pathways

Nonradiological Unit Factors

The nonradiological unit factors were compiled using available references containing the statistical data. The factors reflecting the effect from pollutants generated during normal transport were taken from Reference 5. These factors have values specified only for truck and rail in an urban population zone. The overall (occupational and nonoccupational) traumatic injury and fatality rates for truck transport are those specified in Reference 6. The values used were those specifically evaluated for truck and trailer rigs similar to those that would be used to transport wastes to a repository. In order to unfold the occupational (drivers) injury and fatality rates from the nonoccupational rates, the data in Reference 7 were used. The rail unit factors were calculated from railcar miles given in Reference 8 and fatalities and injuries recorded in Reference 9.

Distances

Truck and rail routes were not generated for each individual reactor site. Instead, a number of reactor centroids were defined and transportation distances were calculated from the centroids to the the appropriate destinations. All of the reactors in a particular National Electric Reliability Council (NERC) region were identified. The NERC region was then divided into subregions based upon the geographic location of the reactors. Once the reactors in a particular subregion were identified, the geographic centroid was calculated from the latitude and longitude of each unit within the subregion. The nearest town to this calculated point that was included in both the HIGHWAY and INTERLINE data bases was selected as the centroid for routing shipments. Actual locations were used for the other sources of waste.

The methods used to calculate the distances from the sources to the destinations have been discussed in an earlier section.

Number of Shipments

The shipment of spent fuel assemblies to a reprocessing plant or possible repository site was based on maintaining a full-core reserve at each reactor storage pool The storage pool capacity and individual reactor discharges were taken from Reference 3. The predicted storage requirements agree on an assembly basis with Reference 3. The storage requirements were then converted to a shipping schedule using the basic assumption that all casks shipped would be fully loaded.

The total number of spent fuel shipments associated with each centroid was compiled from the individual shipping schedules for each reactor in the subregion. Twenty-one subregions were identified. Some subregions contain only a single reactor while others contain up to 12 reactors. Hence, the number of spent fuel shipments is a function of the particular subregion and the capacity of the shipping cask. While both PWR and BWR assemblies are shipped, characteristics of PWR assemblies were used in these calculations.

The number of shipments for the other waste types was calculated using the information about waste volumes in Table 1 and container volumes and package capacity in Table 2.

Fraction of Travel in Population Zones

As the first step in calculating the fraction of travel in population zones, 1980 population density estimates were calculated for a 3′ x 3′ latitude-longitude grid system (376 000 cells) across the US. The most detailed census data that is available at a consistent geographical level across the complete US consists of population counts for enumeration districts in rural areas and block groups in urban areas. (Both will be referred to as "districts" from this point.) The geographic boundary of districts changed from 1970 to 1980, but the Census Bureau did not digitize the 1980 centroids (which are based on the shape of the district) as had been done for the 1970 data. Thus, a technique was developed to distribute 1980 population counts to the 1970 centroids so that a geographic distribution could again be calculated using 1980 data. This technique prorated the 1980 county population down to all the districts within the county on the basis of percent change between 1970 and 1980 while maintaining the 1970 population distribution within the county.

There are approximately 350 000 districts covering the US. Since this study was done on a national basis, the densities were calculated using a centroid-assignment technique. This method assigns each district centroid and its population count to the particular grid cell inside of which it falls. When two or more centroids fall within a given cell, the sum of the populations was calculated for that cell. The total number of people was divided by the area of the cell to calculate a density level.

The population density data base was contoured to generate the specific population densities used in

RADTRAN II. The geographic location of each individual contour was saved in a separate data base so that it could be combined with the transportation routes. The next step involved intersecting the population density contour lines with the transportation routes and calculating the distance of each route that fell within one of the population density zones. The distance in kilometers that each part of a route traversed through a particular zone was accumulated and percentages of travel were calculated. Average percentages were calculated for each repository region and the reprocessing site.

Combining Parameters

The combination of unit factors, distances, numbers of shipments, and fraction of travel in various population zones was performed by a simple computer program. Figure 5 diagrams the scenario pathways. For the reprocessing scenario, paths B, C, D, and E are combined. Paths A, D, and E are totaled for the once-through scenario. Detailed results for each of the paths were also generated.

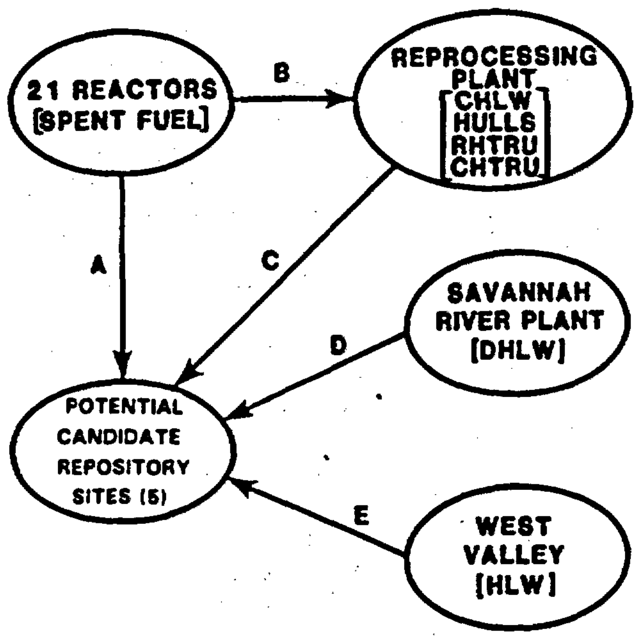

Figure 5. Scenario Pathways

Special Calculation for an Individual Receiving a Maximum Radiological Exposure

One other type of radiological impact, which is not calculated by RADTRAN II, was considered: an hypothetical maximum exposure to an individual who lives beside a rail road track or highway. This dose is calculated by the following equation together with the assumption that the person lives 30 m from the highway or rail track and that all the trucks and trains pass by at 24 km/h.

$$\text{Dose/shipment (mrem)} = 2.0 \times 10^{-3} (K/v)\, I(x), \quad (1)$$

where

$$I(x) = \int_x^{\infty} \frac{e^{-ur} B(r)\, dr}{r(r^2 - x^2)^{1/2}} ,$$

K = dose rate factor (mrem-m^2/h)

x = perpendicular distance of individual from shipment path (m)

v = average velocity (kph) of the shipment passing that point

r = distance of individual from the vehicle passing (m)

B(r) = Berger buildup factor for exposure increase. As a photon beam travels toward a target, some of the energy is attenuated by collisions with air molecules. This is expressed by the exponential decay function, e^{-ur}. However, some of the scattered energy will be rescattered back towards the target. The Berger buildup factor accounts for this and is defined as:

$$B(r) = 0.0006\, r + 1.$$

u = absorption coefficient for air ($3.87 \times 10^{-3} m^{-1}$)

The values for (2.0×10^{-3}) I(x) versus distance are plotted in Figure 6. The values read from this curve can then be adjusted for the particular vehicle speed and dose-rate factor to produce a unit factor per shipment. The product of the unit factor and number of shipments is then summed over each scenario waste type.

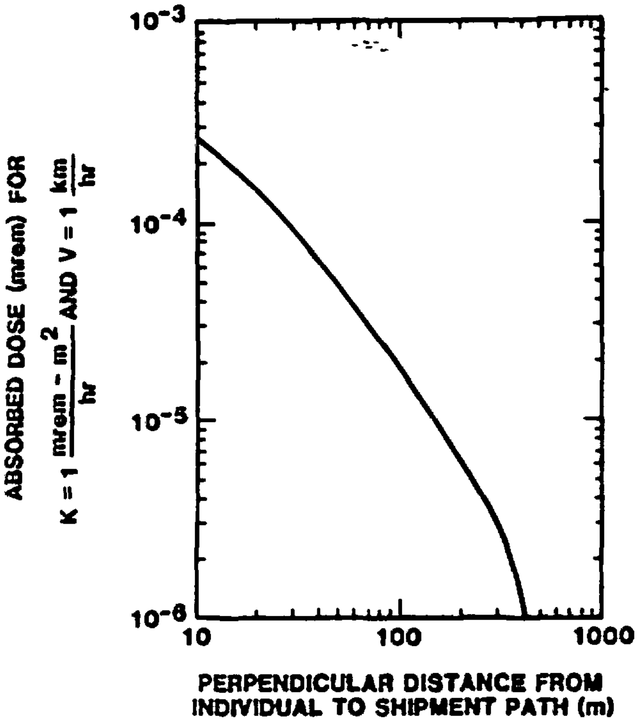

Figure 6. Values for (2.0×10^{-3}) I(x) vs Distance

Input and Assumptions

The calculation of risk involves a great amount of input and a number of assumptions. Much of the input used in this report has been compiled elsewhere so detailed lists of parameters will be referenced where possible. The assumptions used were intended to be consistent with guidance from the Nuclear Waste Terminal Storage program and are consistent with past transportation risk studies that have been performed by or used by the Transportation Technology Center at Sandia National Laboratories, Albuquerque.

Radiological Unit Factors

Since the radiological unit factors were calculated using RADTRAN II, the input required for this analysis is identical to that for the code. RADTRAN II requires significant amounts of data; therefore the code is designed so that much of the input data is contained in the code and only data that is needed for a specific problem need be input. This default data can be found in Reference 10. Only data required for this analysis are presented in this section; other information is default data.

Tables 17 and 18 contain the majority of input data used in this analysis. Table 17 contains data for the truck mode, while Table 18 contains data for the rail mode. Along the left edge of each table are the major categories of input data: shipment, package, and material. Input to each of these categories is given for each of the waste types as first shown in Figures 2a and 2b. Since a detailed radionuclide inventory (as defined by the Office of NWTS Integration) was not available for boiling-water-reactor (BWR) wastes when this analysis was initiated, only pressurized-water-reactor (PWR) waste was analyzed. Therefore, it has been implicitly assumed that, on a basis of a metric ton of heavy metal in the spent fuel, the radionuclide inventory for BWR waste is the same as PWR waste.

The first major category of input is the shipment description. For each type of waste, the number of packages per shipment (PKGSHP) is specified along with the transport index (TIPKG) in mrem per hour at one meter from the package for each shipment. All shipments were assumed to be made in single packages except for rail shipments of contact-handled transuranic (CHTRU) waste. Regulations prevent the dose rate from exceeding 10 mrem/h at 2 m (this is equivalent to a TIPKG of 20), so waste types that will have "new generation" packagings developed were assumed to just meet the regulations. The TIPKG for the CHTRU wastes is lowest because they contain little penetrating radiation; the TIPKG for remote-handled transuranic (RHTRU) wastes is lower than the regulations because it was assumed to be shipped in the same packaging as the Savannah River DHLW, even though it has less penetrating radiation than the DHLW. The DHLW cask was used as a reference since its cavity size can be changed by inserting different size shielding sleeves.

The second major category is package description (PKGCDM). The only nondefault parameter is the maximum dimension that characterizes the package.

The third category is material description. A few of the basic assumptions about the waste materials are given below. PWR spent fuel was 3.2% enriched with a burnup of 32 717 MWd/tHM at a power of 38.4 MW(t)/tHM. The spent fuel was assumed to contain 0.46 tHM/fuel assembly. The fuel age is assumed to be 10 yr out of reactor. The CHLW is also 10 yr old and contains the isotopes of the spent fuel according to the following fractions: 0.005 uranium and plutonium, 0.995 of all other heavy metals, and 0.995 of the important fission products. The cladding hulls from the spent fuel contain the following fractions of the spent fuel: 0.0005 of all heavy metals, 0.0005 of fission products, and 1.0 of activated hull material. The CHTRU waste contains 10^{-7} of the spent fuel inventory and the RHTRU waste contains 10^{-3} of the spent fuel inventory. The DHLW inventory is from Reference 12 and the WVHLW inventory is from Reference 13.

Each of the waste types contains a large number of radioisotopes. In the cases where the types of isotopes had similarities, the input data were homogenized and input as though there were only one radionuclide. Such homogenization could be performed for the high-level wastes, which contain primarily fission products. The values for the homogenized isotopes are found in Tables 17 and 18. Values are given for the total number of curies in the package (CIPKG), the average total photon energy per disintegration (PHTENG), the rate at which released material is deposited on the ground (VELDEP), the cloudshine dose factors (CLDOSF), the physical character of the waste (1 = nondispersible and 2 = immobolized) (IMMAT), the half life (TABHLF), and the ICRP-26 equivalent whole body dose conversion factor (RPCVAL) (see Reference 10).

Table 17. Input Parameters for RADTRAN II (truck)

	Spent Fuel	CHLW	Hulls	CHTRU Waste	RHTRU Waste	DHLW	WVHLW
Shipment							
PKGSHP	1	1	1	1	1	1	1
TIPKG	20	20	20	2	4	20	20
Package							
PKGCDM(m)	5.2	4.6	4.6	7.6	4.6	4.6	4.6
Material							
CIPKG*	2.2×10^5	4.3×10^6	1.5×10^3	0.14	610	1.7×10^5	1.1×10^5
PHTENG (MeV)	**	0.40	0.89	**	**	0.25	0.34
VELDEP (m/s)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CLDOSF $\left(\frac{\text{mrem-cm}^3}{\mu\text{Ci-yr}}\right)$	**	0.059	0	**	**	0.038	0.056
IMMAT	***	2	1	2	2	2	2
TABHLF (days)	**	12 000	1180	**	**	10 000	12 000
RPCVAL $\left(\frac{\text{rem}}{\text{Ci}}\right)$	**	2.8×10^6	NA	**	**	1.8×10^6	7.8×10^5

*Reflects contribution of these isotopes providing 99.9% of radiological hazards when calculated according to: RAD HAZ = ISOTOPE INVENTORY (CI)/MPC_{air}

**see below

	PHTENG	CLDOSF	TABHLF	RPCVAL	Spent Fuel CIPKG	CHTRU Waste CIPKG	RHTRU Waste CIPKG
Co60	2.5	0.45	1910	2.2×10^5	48	3.1×10^{-5}	0.14
Sr90	0	1.7×10^{-8}	10 000	1.1×10^6	5.2×10^4	3.4×10^{-2}	150
Ru106	0.19	0.035	368	5.0×10^5	500	3.3×10^{-4}	1.4
Eu155	1.2	0.22	5800	1.8×10^5	4200	2.7×10^{-3}	12
Cs	0.68	0.11	11 000	3.7×10^4	8.0×10^4	5.2×10^{-2}	230
Pu	0.06	3.2×10^{-4}	7.9×10^5	7.7×10^7	7.8×10^4	5.1×10^{-2}	220
Kr	0.002	3.9×10^{-4}	3930	0.29	4460	NA	NA

***See Reference 11

Table 18. Input Parameters for RADTRAN II (rail)

	Spent Fuel	CHLW	Hulls	CHTRU Waste	RHTRU Waste	DHLW	WVHLW
Shipment							
PKGSHP	** (except 2 packages for CHTRU waste)						
TIPKG	**						
Package							
PKGCDM (m)	**						
Material							
CIPKG*	1.3×10^6***	5.2×10^6	6000	0.46***	2500***	8.5×10^5	7.7×10^5
PHTENG (MeV)	**						
VELDEP (m/s)	**						
CLDOSF $\left(\frac{\text{mrem-cm}^3}{\mu\text{Ci-yr}}\right)$	**						
IMMAT	**						
TABHLF (days)	**						
RPCVAL $\left(\frac{\text{rem}}{\text{Ci}}\right)$	**						

*Reflects contribution of these isotopes providing 99.9% of radiological hazards when calculated according to: RAD HAZ = ISOTOPE INVENTORY (CI)/MPC_{air}

**Same as truck

***

	Spent Fuel CIPKG	CHTRU Waste CIPKG	RHTRU Waste CIPKG
Co60	290	5.0×10^{-5}	0.56
Sr90	3.1×10^5	5.6×10^{-2}	600
Ru106	3000	5.6×10^{-4}	5.6
Eu155	2.5×10^4	4.4×10^{-3}	48
Cs	4.8×10^5	8.6×10^{-2}	920
Pu	4.7×10^5	8.6×10^{-2}	880
Kr	2.7×10^4	NA	NA

In the cases where such homogenization was not deemed acceptable (eg, actinides plus fission products plus activation products), several isotopes for each waste type were considered. In determining which isotopes contributed 99.9% of the relative hazard, the relative hazard for each component isotope was calculated according to:

$$\frac{\text{Isotope Inventory (Ci)}}{\text{Maximum Permissible Concentration in Air}} = \text{Radiological Hazard} \quad (2)$$

Then, the contribution of each isotope to the total relative hazard was determined. Those isotopes contributing less than 0.1% to the total were dropped from the analysis. The list of isotopes for spent fuel, CHTRU waste, and RHTRU waste are shown at the bottom of Table 17 and Table 18.

In light of recent work defining accident parameters for spent fuel shipments (Reference 11), nondefault parameters for accident and release data were input to RADTRAN II as displayed in Table 19. All of the values were obtained from Reference 14, which was a report produced from a workshop conducted on spent fuel shipment accident scenarios.

The first row of values are for truck accident rates (ARATMZ) developed from actual spent fuel shipping experience. The overall accident rate was given in Reference 15 and unfolded, using RADTRAN η and δ factors (Reference 16) to given accident rates by population zone. Because so little rail shipment of spent fuel has been accomplished, the default rail accident values were selected. The next set of parameters (SEVFRC) define the fraction of accidents that occur which are of a particular accident severity. It should be noted that work performed in Reference 11 does not allow expanding the number of severity categories to eight, which is the number used as default in RADTRAN II. Values are given for truck and rail modes.

The remainder of the parameters in the table relate to the amount of material that can be released and subsequently inhaled by the public. RFRAC defines how much material of all sizes can be released from the packages. AERSOL accounts for the fraction of material released that can be entrained in an aerosol, while RESP accounts for the fraction of material that is aerosolized that is also respirable. The product of these three parameters times the number of curies in the package defines the fraction of material released that can be inhaled.

Two additional parameters that are extremely important to the analysis are the amount of time that a shipment stops during transit and the health-effects conversion factor. The stop-time values used for the truck mode have been obtained by documenting many shipments of radioactive material. The value for the rail mode was calculated by assuming that rail shipments average 9.7 kph when stop time is included and, when they are moving, they travel 24 kph, 40 kph, and 64 kph in urban, suburban, and rural areas, respectively. (See Table 23 for definitions). Specifically, the values used in this analysis are 0.011 h/km for truck travel and 0.086 h/km for rail. A factor that converts equivalent whole body dose to latent cancer was necessary for the analysis. The value used was 2×10^{-4} latent cancers (in this and future generations) per person-rem exposure. (This value is relevant when applied to a dose received by a large population. It was not applied to the dose received by the individual exposed to the maximum extent.)

The result of using these values in RADTRAN II is found in Tables 20 and 21, which contain the unit factors for each of the seven waste types. Factors were calculated for each of the three population zones and for both normal and accident conditions of transport. Further subcategorization is for truck and rail modes as well as occupational and nonoccupational exposures for the normal conditions. Nonoccupational doses generally refer to the exposure of the public, which in RADTRAN II is further subcategorized to include people at stops, people living near the route, and people traveling along the same route as the shipment. The doses at stops clearly dominate, however. Observe that the unit factors are presented in terms of person-rem per kilometer of travel.

Nonradiological Unit Factors

The nonradiological unit factors are presented in Table 22. These factors are categorized according to normal and accident conditions of transport for truck and rail modes. The normal factors are for only urban areas and are for nonoccupationally exposed people. Their values are in latent cancer fatalities per kilometer that result from the pollutants.

The accident factors are for both immediate, traumatic fatalities and injuries. The nonoccupationally exposed public includes all people except the truck or train crews, which are included in the occupationally exposed group.

Distances

Some of the distances that waste shipments were required to travel are different for each of the fuel cycle scenarios. For the once-through scenario, spent fuel travels directly from a reactor to a repository. For the reprocessing scenario, the spent fuel travels to the reprocessing site, and the reprocessor ships the waste, generated by recovering the reusable fuel, to a repository. The WVHLW and DHLW travels only to a repository in either scenario.

A simplifying assumption was made to reduce the number of the computations. Instead of calculating distances from each reactor site to each of the repositories and to the reprocessing facility, 21 centroids were established to represent the locations of the ~80 operating reactors in the country today.

Tables 3 and 4 present the distances used in evaluating the risks. Table 3 contains highway distances and Table 4 contains rail distances.

Table 19. Special Parameters for RADTRAN II (spent fuel)*

ARATMZ**	URBAN	SUBURBAN	RURAL
Truck	4.7×10^{-6}	8.1×10^{-7}	4.0×10^{-8}
Rail	1.5×10^{-5}	1.9×10^{-6}	1.0×10^{-7}

	Severity Category						
	1	2	3	4	5	6	7 & 8
SEVFRC							
Truck							
Urban	0.604	0.395	3.8×10^{-4}	3.8×10^{-7}	2.5×10^{-7}	1.3×10^{-7}	NA
Suburban	0.602	0.394	4.0×10^{-3}	4.0×10^{-6}	3.0×10^{-6}	2.0×10^{-6}	NA
Rural	0.603	0.394	3.0×10^{-3}	3.0×10^{-6}	5.0×10^{-6}	7.0×10^{-6}	NA
Rail							
Urban	0.624	0.375	3.8×10^{-4}	3.8×10^{-7}	2.5×10^{-7}	1.3×10^{-7}	NA
Suburban	0.622	0.374	4.0×10^{-3}	4.0×10^{-6}	3.0×10^{-6}	2.0×10^{-6}	NA
Rural	0.623	0.374	3.0×10^{-3}	3.0×10^{-6}	5.0×10^{-6}	7.0×10^{-6}	NA
AERSOL							
Co60	0	0	1	1	1	1	NA
Kr	0	0	0	1	1	1	NA
Cs	0	0	0	1	1	1	NA
Sr, Ru, Pu, Eu	0	0	0	1	1	1	NA
RESP							
Co60	0	0	0.05	0.05	0.05	0.05	NA
Kr	0	0	0	1	1	1	NA
Cs	0	0	0	0.05	1	1	NA
Sr, Ru, Pu, Eu	0	0	0	0.05	0.05	0.05	NA
RFRAC							
Co60	0	0	0.012	0.012	0.012	0.012	NA
Kr	0	0	0	0.01	0.1	0.11	NA
Cs	0	0	0	1×10^{-8}	2×10^{-4}	2.8×10^{-4}	NA
Eu, Sr, Pu	0	0	0	1×10^{-8}	5×10^{-8}	5×10^{-8}	NA
Ru	0	0	0	1×10^{-8}	1×10^{-6}	4.2×10^{-5}	NA

NA Not applicable
*Basis is Reference 11
**Newer data, which are used in the nonradiological assessment, have not yet been incorporated into RADTRAN II.

Table 20. Radiological Unit Factors for Truck (person-rem/km)

UNIT FACTOR	CHTRU Waste			Hulls			DHLW		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal									
Nonoccupational	2.8×10^{-5}	4.3×10^{-5}	5.5×10^{-5}	1.3×10^{-4}	2.1×10^{-4}	2.6×10^{-4}	1.3×10^{-4}	2.1×10^{-4}	2.6×10^{-4}
Occupational	4.6×10^{-6}	1.0×10^{-6}	1.7×10^{-5}	2.6×10^{-5}	5.7×10^{-5}	9.6×10^{-5}	2.6×10^{-5}	5.7×10^{-5}	9.6×10^{-5}
Accident									
Nonoccupational	7.1×10^{-16}	1.0×10^{-12}	3.4×10^{-12}	1.2×10^{-14}	1.4×10^{-12}	3.9×10^{-12}	4.9×10^{-10}	7.4×10^{-7}	2.6×10^{-6}

	Spent Fuel			CHLW			RHTRU Waste		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal									
Nonoccupational	1.5×10^{-4}	2.3×10^{-4}	2.9×10^{-4}	1.3×10^{-4}	2.1×10^{-4}	2.6×10^{-4}	3.3×10^{-6}	4.9×10^{-6}	6.3×10^{-6}
Occupational	3.0×10^{-5}	6.5×10^{-5}	1.1×10^{-4}	2.6×10^{-5}	5.7×10^{-5}	9.6×10^{-5}	5.2×10^{-6}	1.1×10^{-5}	1.9×10^{-5}
Accident									
Nonoccupational	1.8×10^{-10}	5.5×10^{-7}	1.6×10^{-6}	2.0×10^{-9}	3.1×10^{-6}	1.1×10^{-5}	3.1×10^{-12}	4.5×10^{-9}	1.5×10^{-8}

	WVHLW		
	Rural	Suburban	Urban
Normal			
Nonoccupational	1.3×10^{-4}	2.1×10^{-4}	2.6×10^{-4}
Occupational	2.6×10^{-5}	5.7×10^{-5}	9.6×10^{-6}
Accident			
Nonoccupational	4.7×10^{-10}	7.0×10^{-7}	2.5×10^{-6}

Table 21. Radiological Unit Factors for Rail (person-rem/km)*

UNIT FACTOR	CHTRU Waste			Hulls			DHLW		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal									
Nonoccupational	8.6×10^{-4}	8.6×10^{-4}	8.6×10^{-4}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}
Occupational	1.3×10^{-7}	1.3×10^{-7}	1.3×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}
Accident									
Nonoccupational	1.5×10^{-15}	3.1×10^{-12}	4.5×10^{-11}	2.9×10^{-14}	3.2×10^{-12}	9.0×10^{-12}	1.5×10^{-9}	3.2×10^{-6}	5.2×10^{-6}

UNIT FACTOR	Spent Fuel			CHLW			RHTRU Waste		
	Rural	Suburban	Urban	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal									
Nonoccupational	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}	4.9×10^{-4}	4.9×10^{-4}	4.9×10^{-4}
Occupational	4.2×10^{-7}	4.2×10^{-7}	4.2×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}	9.6×10^{-8}	9.6×10^{-8}	9.6×10^{-8}
Accident									
Nonoccupational	2.3×10^{-9}	6.6×10^{-6}	2.6×10^{-5}	1.4×10^{-8}	3.0×10^{-5}	4.9×10^{-4}	7.9×10^{-12}	1.6×10^{-8}	2.4×10^{-7}

UNIT FACTOR	WVHLW		
	Rural	Suburban	Urban
Normal			
Nonoccupational	2.1×10^{-3}	2.1×10^{-3}	2.1×10^{-3}
Occupational	4.0×10^{-7}	4.0×10^{-7}	4.0×10^{-7}
Accident			
Nonoccupational	2.0×10^{-9}	4.2×10^{-6}	6.9×10^{-5}

*Based on railcar kilometers

Table 22. Nonradiological Unit Factors

	Truck			Rail *		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal						
Nonoccupational (latent cancers/km)	—	—	1.0×10^{-7}	—	—	1.3×10^{-7}
Accident						
Nonoccupational fatalities/km	5.3×10^{-8}	1.3×10^{-8}	7.5×10^{-9}	1.7×10^{-8}	1.7×10^{-8}	1.7×10^{-8}
(Injuries/km)	(8.0×10^{-7})	(3.8×10^{-7})	(3.7×10^{-7})	(3.3×10^{-8})	(3.3×10^{-8})	(3.3×10^{-8})
Occupational fatalities/km	1.5×10^{-8}	3.7×10^{-9}	2.1×10^{-9}	1.4×10^{-9}	1.4×10^{-9}	1.4×10^{-9}
(Injuries/km)	(2.8×10^{-8})	(1.3×10^{-8})	(1.3×10^{-8})	(1.9×10^{-7})	(1.9×10^{-7})	(1.9×10^{-7})

*Based on railcar kilometers

Number of Shipments

The numbers of truck and rail shipments used in each fuel cycle scenario are given in Table 5. The same number of shipments of spent fuel, DHLW, and HLW for West Valley was made for each reprocessing scenario. A new type of waste shipment was added with the reprocessing scenario. In the table it is referred to as reprocessing waste, which is composed of four varieties of waste: CHLW, hulls, remote-handled transuranic waste, and contact-handled transuranic waste.

Fractions of Travel in Population Zones

The population density surrounding a site and the population densities of the regions across which shipments must be moved to reach it can influence the overall risk. The fraction of travel in various population zones for the origin/destination distances given in Tables 3 and 4 was determined for each of the repository sites and the reprocessing center. Values are given in Table 23 for truck and rail modes.

Table 23. Percent of Travel in Various Population Densities Along Routes to Different Destinations

	Population Zone*		
Destination	Rural	Suburban	Urban
Truck			
Reprocessing Site	70.7	27.1	2.2
Yucca Mt	83.7	15.2	1.1
Permian	76.8	22.1	1.1
GIR	74.1	24.8	1.1
Paradox	82.4	16.5	1.1
Hanford	81.9	17.2	0.9
Rail			
Reprocessing Site	69.5	28.1	2.4
Yucca Mt	83.1	15.5	1.4
Permian	79.3	19.5	1.2
GIR	75.3	23.1	1.6
Paradox	81.8	16.8	1.4
Hanford	83.2	15.7	1.1

*Rural corresponds to 6 people/km² (mean density)
Suburban corresponds to 719 people/km² (mean density)
Urban corresponds to 3861 people/km² (mean density)

Individual Exposed to the Maximum Extent

The maximum individual dose is calculated by using Eq 1 and by assuming that the person lives 30 m from the highway or rail track and that the trucks or trains pass at 24 km/h. Each shipment is assumed to pass this individual.

Results for Radiological Analysis

As discussed in an earlier section, the overall risk of shipping to a repository is a composite of several different risks. The results of this analysis are presented in two major categories: radiological and nonradiological risk. In addition, the radiological consequence to an individual exposed to the maximum extent is presented.

Radiological Impacts

Tables 24 and 25 contain the calculated values for radiological impacts of transporting to each of five regions for each scenario. Not shown in the tables is the relative contribution of each waste type; however, in each scenario the spent fuel shipments are the largest contributor to risk. A detailed listing of results by waste type is given in Appendix B.

A number of general observations can be made about the results:

1. All projected impacts are small compared with radiological and nonradiological risk already existing in daily life.
2. Rail transport has a greater radiological impact than truck transport.
3. Accidents are expected to contribute in a very small portion of the total radiological impact.
4. The exposure to the public at stops dominates the impact.
5. The results are clearly a function of the distance traveled.

A yardstick by which the magnitude of the numbers in the tables can be judged is provided by applying the health effects conversion factor to the natural background radiation dose received by the population of the United States. Assuming that each member of the public is exposed to an annual dose of 0.1 rem, the number of latent cancer fatalities that would be attributable to background radiation sources (terrestrial and cosmic) would be around 4500 per year or 117 000 for the 26 yr of repository shipment receiving. The largest expected radiological impact is less than 0.0003 of that value.

Table 24. Radiological Impacts — Once-Through (latent cancer fatalities for 26-yr operating period)

	Repository				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Truck					
Normal					
Occupational	1.1	1.5	1.8	2.1	2.4
Nonoccupational	4.8	6.5	8.1	9.6	11
Accident					
Nonoccupational	0.005	0.006	0.006	0.007	0.008
TOTAL	6.0	8.0	10	12	13
Rail					
Normal					
Occupational	0.002	0.003	0.004	0.005	0.005
Nonoccupational	13	16	20	25	26
Accident					
Nonoccupational	0.01	0.01	0.01	0.02	0.02
TOTAL	13	16	20	25	26

Table 25.—Radiological Impacts — Reprocessing (latent cancer fatalities for 26-yr operating period)

	Repository				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Truck					
Normal					
Occupational	1.5	2.0	2.3	2.6	2.8
Nonoccupational	6.2	8.8	11	12	13
Accident					
Nonoccupational	0.01	0.02	0.02	0.02	0.02
TOTAL	7.7	11	13	14	16
Rail					
Normal					
Occupational	0.003	0.004	0.006	0.006	0.007
Nonoccupational	17	24	31	35	36
Accident					
Nonoccupational	0.02	0.03	0.04	0.04	0.04
TOTAL	17	24	31	35	36

Even though the number of shipments is reduced by using rail transport, the impact of rail is greater than truck because trains travel more slowly than trucks, stop for longer periods, and generally must travel longer distances to reach the same destination from the same origin. Despite the factor of 2 difference between the two modes and the differences among the sites, caution must be exercised in making judgments about the relative safety (lack of risk) of the two modes and five sites because of the uncertainties in the analysis (refer to uncertainties section). Accidents are not expected to be large contributors to the overall impact of transportation because of the unlikelihood that one resulting in a release of material will occur. Even if one should occur, experimental evidence suggests that the consequences would not be great (refer to maximum radiological consequences from an accident section). The exposure to the public at stops clearly dominates the radiological impacts.

Nonradiological Impacts

Tables 26 and 27 contain the values for nonradiological impacts of transporting to each of five regions for each reprocessing scenario. The contribution of shipments of each waste type are not given in these tables but can be found in Appendix B.

The nonradiological impacts suggest that (1) impacts increase linearly with distance traveled; (2) the public are subject to the greatest impact; and (3) the impacts are small relative to those of general commerce. These observations are consistent with those made from radiological impacts. However, two additional observations are significantly different from radiological impacts. The number of nonradiological fatalities from truck is much greater (with significant difference) than from rail, and the dominant impact when nonradiological risks are considered is from accidents.

To place the values in the tables in perspective, in 1980 alone, truck-related accidents resulted in 2528 fatalities while rail transport resulted in 1242 radiological fatalities. Extrapolating to 26 yr, these values become 65 000 and 32 000, respectively.

Individual Exposed to the Maximum Extent

Exposure to an individual who sits 30 m away from each truck or rail shipment to the repository was calculated for the once-through and reprocessing scenarios. These impacts are shown in Table 28. They are given in terms of millirem cumulative dose and have not been multiplied by the health-effects conversion factor.

Table 26. Nonradiological Impacts — Once-Through (for 26-yr period)

	Repository				
	GIR	Permain	Paradox	Yucca Mt	Hanford
Truck					
Normal					
Nonoccupational	0.3	0.5	0.6	0.6	0.7
Accident—Fatalities					
Occupational	3.3	4.7	6.3	7.7	8.3
Nonoccupational	12	17	22	27	29
TOTAL FATALITIES	15	22	29	36	38
Accident—Injuries					
Occupational	7	9	12	15	16
Nonoccupational	191	268	356	429	464
Rail					
Normal					
Nonoccupational	0.12	0.12	0.19	0.22	0.19
Accident—Fatalities					
Occupational	0.08	0.1	0.12	0.15	0.16
Nonoccupational	0.9	1.2	1.5	1.9	2.0
TOTAL FATALITIES	1.1	1.4	1.8	2.2	2.3
Accident—Injuries					
Occupational	10	13	17	21	22
Nonoccupational	1.8	2.3	3.0	3.6	3.8

Table 27. Nonradiological Impacts — Reprocessing (for 26-yr period)

	Repository				
	GIR	Permain	Paradox	Yucca Mt	Hanford
Truck					
Normal - Latent Cancer Fatalities					
Nonoccupational	1.3	1.3	1.6	1.8	2.2
Accident—Fatalities					
Occupational	5.5	9.6	13	15	17
Nonoccupational	19	34	46	52	60
TOTAL FATALITIES	26	45	61	69	78
Accident—Injuries					
Occupational	11	19	26	29	33
Nonoccupational	321	551	747	837	952
Rail					
Normal - Latent Cancer Fatalities					
Nonoccupational	0.2	0.4	0.5	0.6	0.5
Accident—Fatalities					
Occupational	0.2	0.3	0.4	0.4	0.4
Nonoccupational	2.0	3.2	4.3	5.1	5.2
TOTAL FATALITIES	2.3	3.9	5.1	6.1	6.2
Accident—Injuries					
Occupational	22	35	48	57	58
Nonoccupational	3.8	6.2	8.3	9.9	10

Table 28. Maximum Individual Dose for 26-Yr Period (mrem)

Scenario	Truck	Rail
Once-through	74	12
Reprocessing	46	8

Maximum Radiological Consequence From an Accident

The results presented in the preceding section, which pertain to risk from accidents, are expected values. As such, they reflect the product of the consequences from a spectrum of accidents and the respective probabilities of occurrence for those accidents. Since the estimated consequences of an accident (should it occur) tend to be masked by the very small probabilities, it is instructive to consider the consequences separately. The consequences of accidents that are calcuated by RADTRAN II have upper limits that range into the tens of latent cancer fatalities per occurrence for spent fuel accidents. Such high values are calculated using assumptions that tend to overestimate consequences; as a matter of fact, these values have been shown by recent experiments to be higher than actually might be expected. It must be emphasized, however, that no radiological releases have occurred involving radioactive materials packages designed to the same criteria as the packages considered in this analysis. The only evidence of how much material might be released in an accident is from carefully conducted laboratory experiments.

In some recent experiments, contents of a simulated shipping cask for spent fuel were forced out through an opening in the cask (Reference 17). The opening was considerably larger than could result from an accident (Reference 14). However, the amount of material that could be forced out was so small that, if released under the worst possible meteorological conditions and in an ultrahigh density urban area, no immediate fatalities would result. Experimental evidence combined with conservative (producing the worst impact) assumptions indicate that only one delayed fatality would result, even in an accident that is more severe than the worst credible accident as defined at a workshop of transportation experts (Reference 14). Furthermore, the analysis performed in Reference 17 considered spent fuel that had been only out of the reactor for only 150 days. Spent fuel sent to a repository will most likely be out of a reactor for more than 10 yr and will be considerably less hazardous. No consequence greater than that predicted for spent fuel would be expected for accidents involving the other waste types that will be sent to a repository.

Uncertainties in Risk Calculations

Uncertainties in data and assumptions propagate into the final result of the analysis. When many parameters are needed to produce a result, more uncertainty will likely be introduced.

The radiological and nonradiological risks calculated in this report have different uncertainties associated with them. Since the number of parameters involved in calculating the radiological risk far exceed the number needed for the nonradiological accident risk, the uncertainty associated with the radiological risk is higher than with the nonradiological. Furthermore, most of the parameters used to calculate nonradiological accident risk are based on documented accident reports while often the basis for the radiological and pollutant risk analysis was conservative, engineering judgment. As a result, the uncertainty in the nonradiological accident risks is much lower than other values.

Any estimate of uncertainty will, of necessity, be based on judgment since the uncertainty of values of each parameter used in this analysis may not be well known. Since the radiological calculations and the pollutant risk estimates use conservative values (overestimate results), they probably produce results that are upper limits. As uncertainties are reduced, these results would probably get smaller by as much as one to two orders of magnitude. On the other hand, the nonradiological accident risks might be expected to vary by a factor of 2 higher or lower.

Since relatively large uncertainties are associated with the absolute values for the risks, the tables of results presented in this report are best used to make relative comparisons among potential sites. The same uncertainty will be contained in all results being compared.

Current risk assessment efforts emphasize better definition of inputs and establish the uncertainties associated with them. This will improve reliability of comparative and absolute judgments of risk.

Guidance for Assessing Risk Results for a Mix of Truck and Rail Shipments

This analysis was performed for two cases: all shipments by truck and all shipments by rail. It is reasonable to assume that the actual shipment mix may be somewhere between 100% truck and 100% rail.

The risk results for a mix may be approximated using detailed results that are given by waste type in Appendix B. The proposed guidance in the following text is a simple technique for estimating the risk results, but it neglects the influence of the origin/destination dependency on results for the spent fuel shipments. Minor errors are being introduced when this guidance is followed; however, as long as this is recognized, the results can be useful.

Equation (3) can be applied to risk results for each waste type for a single repository. Then the newly calculated results must be added to produce a new total result for a repository site using the desired mix of modes.

$$\sum^{\text{Waste Type}} \begin{bmatrix} \text{Risk for} \\ \text{X\% Rail, 100-X\% Truck} \end{bmatrix} = \frac{\text{X\%}}{100} \begin{bmatrix} \text{Risk for} \\ \text{100\% Rail} \end{bmatrix} + \frac{(\text{100-X\%}) \begin{bmatrix} \text{No. of Shipments} \\ \text{if 100\% Rail} \end{bmatrix} \begin{bmatrix} \frac{\text{Ci/PKG Rail}}{\text{Ci/PKG Truck}} \end{bmatrix} \begin{bmatrix} \text{Risk for} \\ \text{100\% Truck} \end{bmatrix}}{100 \begin{bmatrix} \text{Number of Truck} \\ \text{Shipments if 100\% Truck} \end{bmatrix}} \quad (3)$$

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APPENDIX A

Detailed Cost Results

Table

Table A1. Spent Fuel Shipments

	Once-Through					
	GIR	Permian	Paradox	Yucca Mt	Hanford	Reprocessing
Truck						
Total Fleet Size	116	132	146	164	170	108
Distance						
km x 10^6	270	360	450	540	590	240
(mi x 10^6)	170	220	280	340	360	150
Shipping Cost						
\$ x 10^6	467	608	735	894	941	418
Rail						
Total Fleet Size	76	86	92	100	100	72
Distance						
km x 10^6	51	64	79	97	100	46
(mi x 10^6)	32	40	49	60	64	29
Shipping Cost						
\$ x 10^6	448	537	608	693	716	411

Table A2. Transportation of Radioactive Waste to GIR (reprocessing fuel cycle, truck shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	31 581	10 826	54 141	23 684	6720	300
Cask capacity, canisters	1	1	1	16	1	1
Total fleet size,						
No. of vehicles	40	14	66	30	8	2
Round trip distance						
km x 10^6	59	20	100	44	12	1.1
(mi x 10^6)	(36)	(12)	(62)	(27)	(7)	(0.7)
Shipping costs						
\$ x 10^6	114	37	188	78	23	2

Table A3. Transportation of Radioactive Waste to Permian (reprocessing fuel cycle, truck shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	31 581	10 826	54 141	23 684	6720	300
Cask capacity, canisters	1	1	1	16	1	1
Cask fleet size, No. of vehicles	56	20	96	42	11	2
Round trip distance km x 10^6	140	48	240	100	29	1.5
(mi x 10^6)	(87)	(30)	(150)	(65)	(18)	(0.9)
Shipping costs $ x 10^6	245	80	402	166	51	3

Table A4. Transportation of Radioactive Waste to Paradox (reprocessing fuel cycle, truck shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	31 581	10 826	54 141	23 684	6720	300
Cask capacity, canisters	1	1	1	16	1	1
Cask fleet size, No. of vehicles	68	24	118	52	13	2
Round trip distance km x 10^6	200	69	340	150	42	1.9
(mi x 10^6)	(120)	(43)	(210)	(94)	(26)	(1.2)
Shipping costs $ x 10^6	354	115	580	239	74	3

Table A5. Transportation of Radioactive Waste to Yucca Mt (reprocessing fuel cycle, truck shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	31 581	10 826	54 141	23 684	6720	300
Cask capacity, canisters	1	1	1	16	1	1
Cask fleet size, No. of vehicles	76	26	128	56	14	2
Round trip distance km x 10^6	230	80	400	170	49	2.3
(mi x 10^6)	(140)	(49)	(250)	(110)	(30)	(1.4)
Shipping costs $ x 10^6	408	133	669	275	86	4

Table A6. Transportation of Radioactive Waste to Hanford (reprocessing fuel cycle, truck shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	31 581	10 826	54 141	23 684	6720	300
Cask capacity, canisters	1	1	1	16	1	1
Cask fleet size,						
No. of vehicles	84	30	142	62	16	2
Round trip distance						
km x 10^6	270	94	470	200	58	2.4
(mi x 10^6)	(170)	(58)	(290)	(130)	(36)	(1.5)
Shipping costs						
(\$ x 10^6)	479	156	785	323	100	4

Table A7. Transportation of Radioactive Waste to GIR (reprocessing fuel cycle, rail shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	2632	2707	13 536	7288	1344	43
Cask capacity, canisters	12	4	4	52	5	7
Cask fleet size,						
No. of vehicles	16	18	82	44	8	1
Round trip distance						
km x 10^6	6.6	6.8	34	18	3.4	0.2
(mi x 10^6)	(4.1)	(4.2)	(21)	(11)	(2.1)	(0.1)
Shipping costs						
\$ x 10^6	59	64	326	118	34	2

Table A8. Transportation of Radioactive Waste to Permian (reprocessing fuel cycle, rail shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	2632	2707	13 536	7288	1344	43
Cask capacity, canisters	12	4	4	52	5	7
Cask fleet size,						
No. of vehicles	20	20	100	54	9	1
Round trip distance						
km x 10^6	13	14	69	37	6.8	0.2
(mi x 10^6)	(8.3)	(8.6)	(43)	(23)	(4.2)	(0.1)
Shipping costs						
\$ x 10^6	97	107	539	192	56	2

Table A9. Transportation of Radioactive Waste to Paradox (reprocessing fuel cycle, rail shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	2632	2707	13 536	7288	1344	43
Cask capacity, canisters	12	4	4	52	5	7
Cask fleet size,						
No. of vehicles	24	24	118	64	11	1
Round trip distance						
km x 10^6	20	20	100	54	10	0.2
(mi x 10^6)	(12)	(12)	(62)	(34)	(6.2)	(0.2)
Shipping costs						
\$ x 10^6	121	133	672	238	70	2

Table A10. Transportation of Radioactive Waste to Yucca Mt (reprocessing fuel cycle, rail shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	2632	2707	13 536	7288	1344	43
Cask capacity, canisters	12	4	4	52	5	7
Cask fleet size,						
No. of vehicles	26	26	124	68	11	1
Round trip distance						
km x 10^6	24	25	120	67	12	0.3
(mi x 10^6)	(15)	(15)	(77)	(41)	(7.6)	(0.2)
Shipping costs						
\$ x 10^6	147	162	817	288	84	2

Table A11. Transportation of Radioactive Waste to Hanford (reprocessing fuel cycle, rail shipments)

	Waste Type					
	CHLW	Hulls	RHTRU	CHTRU	DHLW	WVHLW
Shipments	2632	2707	13 536	7288	1344	43
Cask capacity, canisters	12	4	4	52	5	7
Cask fleet size,						
No. of vehicles	26	26	126	68	12	1
Round trip distance						
km x 10^6	25	26	130	69	13	0.3
(mi x 10^6)	(16)	(16)	(80)	(43)	(7.9)	(0.2)
Shipping costs						
\$ x 10^6	151	166	841	296	87	2

APPENDIX B

Detailed Risk Results

Detailed results are presented for each of the pathways identified in Figure 5.

Table

Table B1. Transportation Risks for DHLW

Radiological—Truck	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	4.3×10^{-2}	1.0×10^{-1}	1.4×10^{-1}	1.9×10^{-1}	1.6×10^{-1}
Normal Nonoccupational Fatalities	1.8×10^{-1}	4.4×10^{-1}	6.2×10^{-1}	8.4×10^{-1}	7.1×10^{-1}
Accident Nonoccupational Fatalities	3.2×10^{-4}	6.1×10^{-4}	6.7×10^{-4}	9.5×10^{-4}	7.7×10^{-4}
Total Fatalities	2.3×10^{-1}	5.4×10^{-1}	7.5×10^{-1}	1.0×10^{0}	8.7×10^{-1}

Radiological—Rail	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	1.3×10^{-4}	2.7×10^{-4}	4.0×10^{-4}	5.1×10^{-4}	4.9×10^{-4}
Normal Nonoccupational Fatalities	7.1×10^{-1}	1.4×10^{0}	2.1×10^{0}	2.7×10^{0}	2.6×10^{0}
Accident Nonoccupational Fatalities	2.6×10^{-4}	9.8×10^{-4}	1.2×10^{-3}	1.4×10^{-3}	1.6×10^{-3}
Total Fatalities	7.1×10^{-1}	1.4×10^{0}	2.1×10^{0}	2.7×10^{0}	2.6×10^{0}

Nonradiological—Truck	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	3.4×10^{-2}	3.4×10^{-2}	4.6×10^{-2}	8.0×10^{-2}	5.6×10^{-2}
Normal Nonoccupational Fatalities	1.4×10^{-1}	3.6×10^{-1}	5.4×10^{-1}	7.4×10^{-1}	6.4×10^{-1}
Accident Nonoccupational Fatalities	5.0×10^{-1}	1.2×10^{0}	1.9×10^{0}	2.6×10^{0}	2.2×10^{0}
Accident Occupational Injuries	2.8×10^{-1}	7.1×10^{-1}	1.1×10^{0}	1.4×10^{0}	1.2×10^{0}
Accident Nonoccupational Injuries	8.1×10^{0}	$2.0 \times 10^{+1}$	$3.1 \times 10^{+1}$	$4.2 \times 10^{+1}$	$3.5 \times 10^{+1}$
Total Fatalities	6.8×10^{-1}	1.6×10^{0}	2.6×10^{0}	3.4×10^{0}	3.0×10^{0}

Nonradiological—Rail	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	2.0×10^{-3}	1.3×10^{-2}	1.6×10^{-2}	1.8×10^{-2}	2.4×10^{-2}
Normal Nonoccupational Fatalities	4.8×10^{-3}	9.6×10^{-3}	1.4×10^{-2}	1.8×10^{-2}	1.7×10^{-2}
Accident Nonoccupational Fatalities	5.8×10^{-2}	1.2×10^{-1}	1.7×10^{-1}	2.2×10^{-1}	2.0×10^{-1}
Accident Occupational Injuries	6.4×10^{-1}	1.3×10^{0}	1.9×10^{0}	2.4×10^{0}	2.4×10^{0}
Accident Nonoccupational Injuries	1.1×10^{-1}	2.2×10^{-1}	3.2×10^{-1}	4.2×10^{-1}	4.0×10^{-1}
Total Fatalities	6.4×10^{-2}	1.4×10^{-1}	2.0×10^{-1}	2.6×10^{-1}	2.6×10^{-1}

Table B2. Transportation Risks for WVHLW

	Radiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	4.0×10^{-3}	5.3×10^{-3}	6.4×10^{-3}	8.1×10^{-3}	7.6×10^{-3}
Normal Nonoccupational Fatalities	1.7×10^{-2}	2.3×10^{-2}	2.8×10^{-2}	3.6×10^{-2}	3.4×10^{-2}
Accident Nonoccupational Fatalities	2.9×10^{-5}	3.4×10^{-5}	3.7×10^{-5}	4.4×10^{-5}	3.9×10^{-5}
Total Fatalities	2.1×10^{-2}	2.8×10^{-2}	3.5×10^{-2}	4.4×10^{-2}	4.2×10^{-2}

	Radiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	8.0×10^{-6}	9.3×10^{-6}	1.2×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
Normal Nonoccupational Fatalities	4.2×10^{-2}	4.9×10^{-2}	6.1×10^{-2}	7.8×10^{-2}	7.8×10^{-2}
Accident Nonoccupational Fatalities	4.6×10^{-5}	3.7×10^{-5}	5.4×10^{-5}	6.1×10^{-5}	5.7×10^{-5}
Total Fatalities	4.2×10^{-2}	4.9×10^{-2}	6.1×10^{-2}	7.8×10^{-2}	7.8×10^{-2}

	Nonradiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	3.0×10^{-3}	1.8×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	4.0×10^{-3}
Normal Nonoccupational Fatalities	1.2×10^{-2}	1.7×10^{-2}	2.4×10^{-2}	3.0×10^{-2}	3.0×10^{-2}
Accident Nonoccupational Fatalities	4.4×10^{-2}	6.2×10^{-2}	8.2×10^{-2}	1.0×10^{-2}	1.0×10^{-2}
Accident Occupational Injuries	2.5×10^{-2}	3.6×10^{-2}	4.6×10^{-2}	5.9×10^{-2}	5.8×10^{-2}
Accident Nonoccupational Injuries	7.3×10^{-1}	1.0×10^{0}	1.3×10^{0}	1.7×10^{0}	1.7×10^{0}
Total Fatalities	6.0×10^{-2}	8.2×10^{-2}	1.1×10^{-1}	1.4×10^{-1}	1.4×10^{-1}

	Nonradiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	4.0×10^{-4}	3.2×10^{-4}	6.0×10^{-4}	6.6×10^{-4}	5.4×10^{-4}
Normal Nonoccupational Fatalities	2.8×10^{-4}	3.2×10^{-4}	4.0×10^{-4}	5.2×10^{-4}	5.2×10^{-4}
Accident Nonoccupational Fatalities	3.4×10^{-3}	4.0×10^{-3}	5.0×10^{-3}	6.2×10^{-3}	6.2×10^{-3}
Accident Occupational Injuries	3.8×10^{-2}	4.4×10^{-2}	5.6×10^{-2}	7.0×10^{-2}	7.0×10^{-2}
Accident Nonoccupational Injuries	6.6×10^{-3}	7.6×10^{-3}	9.6×10^{-3}	1.2×10^{-2}	1.2×10^{-2}
Total Fatalities	4.0×10^{-3}	4.6×10^{-3}	6.0×10^{-3}	7.4×10^{-3}	7.4×10^{-3}

Table B3. Transportation Risks for Hulls

	Radiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	7.2×10^{-2}	1.6×10^{-1}	2.2×10^{-1}	3.0×10^{-1}	2.6×10^{-1}
Normal Nonoccupational Fatalities	3.1×10^{-1}	7.2×10^{-1}	1.0×10^{0}	1.4×10^{0}	1.2×10^{0}
Accident Nonoccupational Fatalities	1.0×10^{-9}	1.9×10^{-9}	2.0×10^{-9}	2.9×10^{-9}	2.4×10^{-9}
Total Fatalities	3.8×10^{-1}	8.8×10^{-1}	1.2×10^{0}	1.7×10^{0}	1.4×10^{0}
	Radiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	2.7×10^{-4}	5.5×10^{-4}	8.0×10^{-4}	1.0×10^{-3}	9.9×10^{-4}
Normal Nonoccupational Fatalities	1.4×10^{0}	2.9×10^{0}	4.2×10^{0}	5.4×10^{0}	5.2×10^{0}
Accident Nonoccupational Fatalities	4.0×10^{-10}	1.1×10^{-9}	1.3×10^{-9}	1.7×10^{-9}	1.8×10^{-9}
Total Fatalities	1.4×10^{0}	2.9×10^{0}	4.2×10^{0}	5.4×10^{0}	5.2×10^{0}
	Nonradiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	5.8×10^{-2}	5.6×10^{-2}	7.6×10^{-2}	1.3×10^{-1}	9.2×10^{-2}
Normal Nonoccupational Fatalities	2.4×10^{-1}	5.8×10^{-1}	9.0×10^{-1}	1.2×10^{0}	1.0×10^{0}
Accident Nonoccupational Fatalities	8.2×10^{-1}	2.0×10^{0}	3.2×10^{0}	4.2×10^{0}	3.6×10^{0}
Accident Occupational Injuries	4.8×10^{-1}	1.2×10^{0}	1.7×10^{0}	2.4×10^{0}	2.0×10^{0}
Accident Nonoccupational Injuries	$1.4 \times 10^{+1}$	$3.3 \times 10^{+1}$	$5.0 \times 10^{+1}$	$6.7 \times 10^{+1}$	$5.8 \times 10^{+1}$
Total Fatalities	1.1×10^{0}	2.6×10^{0}	4.2×10^{0}	5.6×10^{0}	4.8×10^{0}
	Nonradiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	4.2×10^{-3}	2.6×10^{-2}	3.4×10^{-2}	3.6×10^{-2}	4.8×10^{-2}
Normal Nonoccupational Fatalities	9.4×10^{-3}	1.9×10^{-2}	2.8×10^{-2}	3.6×10^{-2}	3.4×10^{-2}
Accident Nonoccupational Fatalities	1.2×10^{-1}	2.4×10^{-1}	3.4×10^{-1}	4.4×10^{-1}	4.2×10^{-1}
Accident Occupational Injuries	1.2×10^{0}	2.6×10^{0}	3.8×10^{0}	4.8×10^{0}	4.8×10^{0}
Accident Nonoccupational Injuries	2.2×10^{-1}	4.6×10^{-1}	6.6×10^{-1}	8.4×10^{-1}	8.2×10^{-1}
Total Fatalities	1.2×10^{-1}	2.8×10^{-1}	4.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}

Table B4. Transportation Risks for CHTRU Waste

	Radiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	2.8×10^{-2}	6.3×10^{-2}	8.6×10^{-2}	1.2×10^{-1}	9.9×10^{-2}
Normal Nonoccupational Fatalities	1.4×10^{-1}	3.3×10^{-1}	4.7×10^{-1}	6.3×10^{-1}	5.4×10^{-1}
Accident Nonoccupational Fatalities	1.6×10^{-9}	2.9×10^{-9}	3.2×10^{-9}	4.5×10^{-9}	3.7×10^{-9}
Total Fatalities	1.7×10^{-1}	4.0×10^{-1}	5.5×10^{-1}	7.5×10^{-1}	6.4×10^{-1}

	Radiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	2.4×10^{-4}	4.8×10^{-4}	7.0×10^{-4}	9.0×10^{-4}	8.7×10^{-4}
Normal Nonoccupational Fatalities	1.6×10^{0}	3.2×10^{0}	4.6×10^{0}	6.0×10^{0}	5.7×10^{0}
Accident Nonoccupational Fatalities	1.3×10^{-9}	4.9×10^{-9}	5.9×10^{-9}	7.0×10^{-9}	8.1×10^{-9}
Total Fatalities	1.6×10^{0}	3.2×10^{0}	4.7×10^{0}	6.0×10^{0}	5.7×10^{0}

	Nonradiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	1.2×10^{-1}	1.2×10^{-1}	1.6×10^{-1}	2.8×10^{-1}	2.0×10^{-1}
Normal Nonoccupational Fatalities	5.2×10^{-1}	1.2×10^{0}	1.9×10^{0}	2.6×10^{0}	2.2×10^{0}
Accident Nonoccupational Fatalities	1.8×10^{0}	4.4×10^{0}	6.8×10^{0}	9.2×10^{0}	8.0×10^{0}
Accident Occupational Injuries	1.0×10^{0}	2.5×10^{0}	3.8×10^{0}	5.2×10^{0}	4.4×10^{0}
Accident Nonoccupational Injuries	$3.0 \times 10^{+1}$	$7.3 \times 10^{+1}$	$1.1 \times 10^{+2}$	$1.5 \times 10^{+2}$	$1.3 \times 10^{+2}$
Total Fatalities	2.4×10^{0}	5.8×10^{0}	9.0×10^{0}	$1.2 \times 10^{+1}$	$1.0 \times 10^{+1}$

	Nonradiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	1.1×10^{-2}	7.2×10^{-2}	9.2×10^{-2}	9.8×10^{-2}	1.2×10^{-1}
Normal Nonoccupational Fatalities	2.6×10^{-2}	5.2×10^{-2}	7.6×10^{-2}	9.6×10^{-2}	9.4×10^{-2}
Accident Nonoccupational Fatalities	3.0×10^{-1}	6.4×10^{-1}	9.2×10^{-1}	1.2×10^{0}	1.1×10^{0}
Accident Occupational Injuries	3.4×10^{0}	7.0×10^{0}	$1.0 \times 10^{+1}$	$1.3 \times 10^{+1}$	$1.2 \times 10^{+1}$
Accident Nonoccupational Injuries	6.0×10^{-1}	1.2×10^{0}	1.7×10^{0}	2.2×10^{0}	2.2×10^{0}
Total Fatalities	3.4×10^{-1}	7.6×10^{-1}	1.0×10^{0}	1.4×10^{0}	1.4×10^{0}

Table B5. Transportation Risks for RHTRU Waste

	Radiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	7.1×10^{-2}	1.6×10^{-1}	2.2×10^{-1}	3.0×10^{-1}	2.5×10^{-1}
Normal Nonoccupational Fatalities	3.8×10^{-1}	8.9×10^{-1}	1.2×10^{0}	1.7×10^{0}	1.4×10^{0}
Accident Nonoccupational Fatalities	1.6×10^{-5}	3.0×10^{-5}	3.3×10^{-5}	4.6×10^{-5}	3.8×10^{-5}
Total Fatalities	4.5×10^{-1}	1.1×10^{0}	1.5×10^{0}	2.0×10^{0}	1.7×10^{0}

	Radiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	3.2×10^{-4}	6.6×10^{-4}	9.6×10^{-4}	1.2×10^{-3}	1.2×10^{-3}
Normal Nonoccupational Fatalities	1.7×10^{0}	3.4×10^{0}	4.9×10^{0}	6.3×10^{0}	6.1×10^{0}
Accident Nonoccupational Fatalities	1.3×10^{-5}	4.7×10^{-5}	5.8×10^{-5}	6.8×10^{-5}	7.9×10^{-5}
Total Fatalities	1.7×10^{0}	3.4×10^{0}	4.9×10^{0}	6.3×10^{0}	6.1×10^{0}

	Nonradiological—Truck				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	3.0×10^{-1}	2.8×10^{-1}	3.8×10^{-1}	6.6×10^{-1}	4.6×10^{-1}
Normal Nonoccupational Fatalities	1.2×10^{0}	3.0×10^{0}	4.4×10^{0}	6.0×10^{0}	5.2×10^{0}
Accident Nonoccupational Fatalities	4.2×10^{0}	$1.0 \times 10^{+1}$	$1.6 \times 10^{+1}$	$2.2 \times 10^{+1}$	$1.8 \times 10^{+1}$
Accident Occupational Injuries	2.4×10^{0}	5.8×10^{0}	8.7×10^{0}	$1.2 \times 10^{+1}$	$1.0 \times 10^{+1}$
Accident Non Occupational Injuries	$6.8 \times 10^{+1}$	$1.7 \times 10^{+2}$	$2.5 \times 10^{+2}$	$3.4 \times 10^{+2}$	$2.9 \times 10^{+2}$
Total Fatalities	5.6×10^{0}	$1.3 \times 10^{+1}$	$2.0 \times 10^{+1}$	$2.8 \times 10^{+1}$	$2.4 \times 10^{+1}$

	Nonradiological—Rail				
	GIR	Permian	Paradox	Hanford	Yucca Mt
Normal Occupational Fatalities	2.2×10^{-2}	1.3×10^{-1}	1.7×10^{-1}	1.8×10^{-1}	2.4×10^{-1}
Normal Nonoccupational Fatalities	4.8×10^{-2}	9.6×10^{-2}	1.4×10^{-1}	1.8×10^{-1}	1.7×10^{-1}
Accident Nonoccupational Fatalities	5.8×10^{-1}	1.2×10^{0}	1.7×10^{0}	2.2×10^{0}	2.2×10^{0}
Accident Occupational Injuries	6.4×10^{0}	$1.3 \times 10^{+1}$	$1.9 \times 10^{+1}$	$2.4 \times 10^{+1}$	$2.4 \times 10^{+1}$
Accident Nonoccupational Injuries	1.1×10^{0}	2.2×10^{0}	3.4×10^{0}	4.2×10^{0}	4.0×10^{0}
Total Fatalities	6.4×10^{-1}	1.4×10^{0}	2.0×10^{0}	2.6×10^{0}	2.6×10^{0}

Table B6. Transportation Risks for Commercial HLW

	GIR	Permian	Paradox	Hanford	Yucca Mt
Radiological—Truck					
Normal Occupational Fatalities	2.1×10^{-1}	4.8×10^{-1}	6.5×10^{-1}	8.8×10^{-1}	7.5×10^{-1}
Normal Nonoccupational Fatalities	9.0×10^{-1}	2.1×10^{0}	2.9×10^{0}	4.0×10^{0}	3.4×10^{0}
Accident Nonoccupational Fatalities	6.5×10^{-3}	1.2×10^{-2}	1.3×10^{-2}	1.9×10^{-2}	1.5×10^{-2}
Total Fatalities	1.1×10^{0}	2.6×10^{0}	3.6×10^{0}	4.9×10^{0}	4.1×10^{0}
Radiological—Rail					
Normal Occupational Fatalities	2.6×10^{-4}	5.4×10^{-4}	7.8×10^{-4}	1.0×10^{-3}	9.6×10^{-4}
Normal Nonoccupational Fatalities	1.4×10^{0}	2.8×10^{0}	4.1×10^{0}	5.2×10^{0}	5.1×10^{0}
Accident Nonoccupational Fatalities	4.8×10^{-3}	1.8×10^{-2}	2.2×10^{-2}	2.5×10^{-2}	3.0×10^{-2}
Total Fatalities	1.4×10^{0}	2.8×10^{0}	4.1×10^{0}	5.3×10^{0}	5.1×10^{0}
Nonradiological—Truck					
Normal Occupational Fatalities	1.7×10^{-1}	1.6×10^{-1}	2.2×10^{-1}	3.8×10^{-1}	2.6×10^{-1}
Normal Nonoccupational Fatalities	6.8×10^{-1}	1.7×10^{0}	2.6×10^{0}	3.6×10^{0}	3.0×10^{0}
Accident Nonoccupational Fatalities	2.4×10^{0}	6.0×10^{0}	9.2×10^{0}	$1.2 \times 10^{+1}$	$1.1 \times 10^{+1}$
Accident Occupational Injuries	1.4×10^{0}	3.4×10^{0}	5.1×10^{0}	6.9×10^{0}	5.9×10^{0}
Accident Nonoccupational Injuries	$4.0 \times 10^{+1}$	$9.7 \times 10^{+1}$	$1.4 \times 10^{+2}$	$2.0 \times 10^{+2}$	$1.7 \times 10^{+2}$
Total Fatalities	3.2×10^{0}	7.8×10^{0}	$1.2 \times 10^{+1}$	$1.6 \times 10^{+1}$	$1.4 \times 10^{+1}$
Nonradiological—Rail					
Normal Occupational Fatalities	4.2×10^{-3}	2.6×10^{-2}	3.4×10^{-2}	3.6×10^{-2}	4.6×10^{-2}
Normal Nonoccupational Fatalities	9.2×10^{-3}	1.9×10^{-2}	2.8×10^{-2}	3.6×10^{-2}	3.4×10^{-2}
Accident Nonoccupational Fatalities	1.1×10^{-1}	2.2×10^{-1}	3.4×10^{-1}	4.2×10^{-1}	4.0×10^{-1}
Accident Occupational Injuries	1.2×10^{0}	2.6×10^{0}	3.8×10^{0}	4.8×10^{0}	4.6×10^{0}
Accident Nonoccupational Injuries	2.2×10^{-1}	4.4×10^{-1}	6.4×10^{-1}	8.2×10^{-1}	8.0×10^{-1}
Total Fatalities	1.3×10^{-1}	2.8×10^{-1}	4.0×10^{-1}	5.0×10^{-1}	4.8×10^{-1}

Table B7. Transportation Risks for Spent Fuel to Reprocessing

Radiological—Truck	
Normal Occupational Fatalities	1.0×10^{0}
Normal Nonoccupational Fatalities	4.3×10^{0}
Accident Nonoccupational Fatalities	5.1×10^{-3}
Total Fatalities	5.3×10^{0}
Radiological—Rail	
Normal Occupational Fatalities	1.9×10^{-3}
Normal Nonoccupational Fatalities	$1.1 \times 10^{+1}$
Accident Nonoccupational Fatalities	1.3×10^{-2}
Total Fatalities	$1.1 \times 10^{+1}$
Nonradiological—Truck	
Normal Occupational Fatalities	6.8×10^{-1}
Normal Nonoccupational Fatalities	2.8×10^{0}
Accident Nonoccupational Fatalities	9.6×10^{0}
Accident Occupational Injuries	5.6×10^{0}
Accident Nonoccupational Injuries	$1.6 \times 10^{+2}$
Total Fatalities	$1.3 \times 10^{+1}$
Nonradiological—Rail	
Normal Occupational Fatalities	1.6×10^{-1}
Normal Nonoccupational Fatalities	6.4×10^{-2}
Accident Nonoccupational Fatalities	7.8×10^{-1}
Accident Occupational Injuries	8.8×10^{0}
Accident Nonoccupational Injuries	1.5×10^{0}
Total Fatalities	1.0×10^{0}

Table B8. Transportation Risks for Spent Fuel to Repository

	GIR	Permian	Paradox	Hanford	Yucca Mt
Radiological—Truck					
Normal Occupational Fatalities	1.1×10^{0}	1.4×10^{0}	1.7×10^{0}	2.2×10^{0}	2.0×10^{0}
Normal Nonoccupational Fatalities	4.6×10^{0}	6.1×10^{0}	7.5×10^{0}	9.7×10^{0}	8.9×10^{0}
Accident Nonoccupational Fatalities	4.5×10^{-3}	5.4×10^{-3}	5.4×10^{-3}	6.9×10^{-3}	5.8×10^{-3}
Total Fatalities	5.7×10^{0}	7.5×10^{0}	9.2×10^{0}	$1.2 \times 10^{+1}$	$1.1 \times 10^{+1}$
Radiological—Rail					
Normal Occupational Fatalities	2.2×10^{-3}	2.7×10^{-3}	3.3×10^{-3}	4.3×10^{-3}	4.1×10^{-3}
Normal Nonoccupational Fatalities	$1.2 \times 10^{+1}$	$1.5 \times 10^{+1}$	$1.8 \times 10^{+1}$	$2.4 \times 10^{+1}$	$2.2 \times 10^{+1}$
Accident Nonoccupational Fatalities	1.1×10^{-2}	1.1×10^{-2}	1.3×10^{-2}	1.5×10^{-2}	1.4×10^{-2}
Total Fatalities	$1.2 \times 10^{+1}$	$1.5 \times 10^{+1}$	$1.8 \times 10^{+1}$	$2.4 \times 10^{+1}$	$2.2 \times 10^{+1}$
Nonradiological—Truck					
Normal Occupational Fatalities	3.0×10^{-1}	4.6×10^{-1}	5.6×10^{-1}	5.4×10^{-1}	6.2×10^{-1}
Normal Nonoccupational Fatalities	3.2×10^{0}	4.4×10^{0}	5.8×10^{0}	7.4×10^{0}	7.0×10^{0}
Accident Nonoccupational Fatalities	$1.1 \times 10^{+1}$	$1.5 \times 10^{+1}$	$2.0 \times 10^{+1}$	$2.6 \times 10^{+1}$	$2.4 \times 10^{+1}$
Accident Occupational Injuries	6.4×10^{0}	8.6×10^{0}	$1.1 \times 10^{+1}$	$1.5 \times 10^{+1}$	$1.4 \times 10^{+1}$
Accident Nonoccupational Injuries	$1.8 \times 10^{+2}$	$2.5 \times 10^{+2}$	$3.2 \times 10^{+2}$	$4.2 \times 10^{+2}$	$3.9 \times 10^{+2}$
Total Fatalities	$1.4 \times 10^{+1}$	$2.0 \times 10^{+1}$	$2.6 \times 10^{+1}$	$3.4 \times 10^{+1}$	$3.2 \times 10^{+1}$
Nonradiological—Rail					
Normal Occupational Fatalities	1.2×10^{-1}	1.1×10^{-1}	1.7×10^{-1}	1.7×10^{-1}	1.9×10^{-1}
Normal Nonoccupational Fatalities	7.2×10^{-2}	9.0×10^{-2}	1.1×10^{-1}	1.4×10^{-1}	1.4×10^{-1}
Accident Nonoccupational Fatalities	8.8×10^{-1}	1.1×10^{0}	1.3×10^{0}	1.7×10^{0}	1.6×10^{0}
Accident Occupational Injuries	9.8×10^{0}	$1.2 \times 10^{+1}$	$1.5 \times 10^{+1}$	$1.9 \times 10^{+1}$	$1.9 \times 10^{+1}$
Accident Nonoccupational Injuries	1.7×10^{0}	2.2×10^{0}	2.6×10^{0}	3.4×10^{0}	3.2×10^{0}
Total Fatalities	1.1×10^{0}	1.3×10^{0}	1.6×10^{0}	1.9×10^{0}	2.0×10^{0}

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Guidance for Developing State and Local Radiological Emergency Response Plans and Preparedness for Transportation Accidents

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