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NUCLEAR AND CHEMICAL WASTE PROGRAMS

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MARTIN MARIETTA

IMPACT OF TRANSPORTING DEFENSE HIGH-LEVEL WASTE TO

A GEOLOGIC REPOSITORY

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Chemical Technology Division

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Energy Division

AUGUST 1984

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
DEPARTMENT OF ENERGY
Contract No. DE-AC05-84OR21400

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1. INTRODUCTION

The Nuclear Waste Policy Act of 1982 (Public Law 97-425) provides for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel. This law requires the Secretary of Energy to evaluate five potential repository sites and to recommend three of the sites to the President, by not later than January 1, 1985, for his selection in order to initiate site characterization of the first repository. Such evaluations take into consideration factors relating to cost efficiency, health and safety, regulation, transportation, public acceptability, and national security.

This transportation study assumes that defense high-level waste is stored in three locations (the Savannah River, Hanford, and Idaho Falls plants) and may be disposed of in (1) a commercial repository or (2) a defense-only repository, either of which could be located at one of the five candidate sites; also documented is a preliminary analysis of the costs and risks of transporting defense high-level waste from the three storage sites to the five potential candidate repository sites.

2. TRANSPORT SCENARIOS

2.1 Regulations

There are four federal agencies that have responsibilities relating to transportation of radioactive waste: the Department of

Transportation (DOT), the Nuclear Regulatory Commission (NRC), the Department of Energy (DOE), and the Interstate Commerce Commission (ICC). Often one agency will certify that its regulations will meet the regulations of another agency. Where areas of overlap or conflicts could exist, memoranda of understanding are issued to define areas of responsibility. In addition to the federal agencies, many states have regulations requiring special actions regarding radioactive material shipments.^{1,16}

Interstate Commerce Commission regulations are related primarily to the economics of transportation. Costs and services may be regulated by the ICC if common carriers are used. If DOE or its contractors should be the prime mover, the ICC would not be involved. The NRC has regulatory authority over commercial shippers but does not have jurisdiction over shipments by DOE. Also, DOE has the authority to design and certify its own packagings and is not required to license its packagings through the NRC. However, the DOE imposes standards equivalent to those of DOT and NRC and certifies that casks will meet corresponding NRC and DOT test criteria. The DOE also submits its certificates to NRC for their review. Because transportation safety is the major concern of this report and because DOT has the major responsibility for the safe transportation of radioactive materials, ICC, NRC, and DOE regulations are not discussed further.

The DOT specifies and enforces regulations to ensure that radioactive materials are properly classified, packaged, labeled,

placarded, and prepared in the required condition for shipment. The DOT is also responsible for enforcing vehicle safety standards, setting allowable radiation levels, and requiring the use of tamper-indicating seals. For rail shipments, DOT specifies the location of the car carrying radioactive cargo in relation to other placarded (hazardous material) cars, the engine, and the caboose.

The Department of Transportation has recently published regulations for highway routing of radioactive materials and the training of drivers.² According to the regulations, the carrier or his agent who operates a motor vehicle carrying a large quantity of radioactive material shall prepare a written route plan and supply a copy, before departure, to the motor vehicle driver and a copy to the shipper. Any deviation from the route plan shall be reported (as an amendment) to the shipper as soon as practical but within 30 days of the shipment. The route plan must state the origin, preferred route, destination, planned stops, estimated departure and arrival times, and telephone numbers which will access emergency assistance in each state on the route.

A preferred route is to consist of Interstate highways using Interstate bypasses or beltways around cities where possible or an alternate route designated by a state routing agency. Although the Interstate highways are normally considered to be the routes of

choice, a motor vehicle may deviate from a preferred route to make necessary rest, fuel, and vehicle repair stops and when emergency conditions make continued use of the preferred route unsafe.

The training requirements stipulate that no person may transport a large quantity of radioactive material on a public highway unless the driver has received, within the two preceding years, training on the properties and hazards of the radioactive materials being transported and the procedures to be followed in case of an accident or other emergency. How to minimize damage to life and property in an emergency, labeling and placarding requirements, and shipment preparation are included in the training. The driver is to have in his immediate possession a certificate showing proof of training and the route plan mentioned above.

2.2 Cask Licensing

The time required to license a cask through the Nuclear Regulatory Commission (NRC) has varied in the past from one to five years³ depending on many factors. This licensing process is generally not initiated until after the cask has been completed, which can add an additional one to two years depending upon the complexity of the packaging.

The cask design and analysis involves a multidisciplinary approach in which structural integrity, heat transfer, and shielding are addressed, as well as quality assurance, fabrication, and systems engineering. The information is gathered together in a Safety Analysis for Packaging (SARP) for submittal to NRC. While the

engineering aspects of the SARP are well understood, the quality assurance aspects are considered very important because it is this part of the program that provides the confidence that the casks are fabricated to the design that will be approved by NRC.

Experience has shown that conceptual design, preliminary design, and final design and analysis will take 12 to 20 months depending upon the complexity of the cask, the manpower committed, etc. Although the SARP preparation may be initiated before the final design is finished, a three to four month period following the completion of the analysis will probably be required to complete the document.

The licensing phase has the greatest uncertainty associated with it. Once the SARP is submitted to NRC, it undergoes an internal review by experts in specific technical areas. These people then generate a list of questions to be submitted back to the originating organization for resolution. This cycle is repeated until all the questions are satisfactorily answered. If the process is carried out efficiently, licensing should take 12 to 36 months to complete. However, experience has shown that for new casks designed to carry large quantities of radioactive material, licensing has taken as much as 60 months.³ As a result, the process, from design initiation to NRC approval, could take as long as 80 months (6.7 years).

While it is not desirable to start fabrication before the cask license has been obtained, frequently materials, particularly long lead items, can be purchased before the license is in hand. If fabrication were to take a year or more to complete, the entire process could take as long as eight years.

2.3 Waste Sources

Three sites shown in Fig. 1 have been identified as producing Defense High Level Waste (DHLW) canisters. These sites are: Hanford, Washington; Idaho Falls, Idaho; and the Savannah River Plant (SRP), South Carolina. Each shipping site has rail service. Both the Burlington Northern and the Union Pacific railroads provide rail service at Hanford, Washington. In this report all rail shipments are assumed to leave Hanford on the Union Pacific Railroad. The Union Pacific also serves the Idaho Falls facility. The Seaboard Coast Line is the railroad providing service at the Savannah River Plant.

2.4 Repository Sites

Five potential repository sites have been identified and the map in Fig. 2 shows the location of these sites. The Basalt site is located near Hanford, Washington; the TUFF site is located at Yucca Mountain on the Nevada Test Site; the Paradox Dome is located in southeastern Utah near Monticello, Utah; the Permian Basin is located near Hereford, Texas; and the Gulf Interior Region site (GIR) is assumed to be located at a salt dome near Richton, Mississippi.

Three of the five receiving sites have rail service near the proposed repository: Hanford, Washington — Union Pacific; Permian — Atchison, Topeka, and Santa Fe; and the GIR — Illinois Central Gulf. The nearest rail line to the Nevada Test Site ends at Las Vegas, Nevada, approximately 100 miles to the south. All rail shipments to

Fig. 1. Locations of Facilities Generating Defense High-Level Waste Canisters.

Fig. 2. Location of Potential Repository Sites.

this site are assumed to arrive in Las Vegas on the Union Pacific Railroad. The nearest rail line to the Paradox site is a spur line on the Denver and Rio Grande Western at Potash, Utah. Potash is located approximately 40 miles north of the Paradox site.

2.5 Canister Flows

Two waste flow scenarios are considered which are related to the total quantity of defense high-level waste which will be placed in a repository. The low-flow case is based on a total of 6700 canisters being transported from the Savannah River Plant. The high-flow case assumes that a total of 20,000 canisters will be transported from three waste generator sites: the Savannah River Plant, Idaho Falls, and Hanford. The annual flow from each source and the total amount of material being received at the repository are identified in Tables 1 and 2 and Figs. 3 and 4. The Permian basin is shown in these two figures as an example only.

In the low-flow case 500 canisters will be shipped each year for a 13-year period starting in 1998. An additional 200 canisters will be shipped in the fourteenth year (2011) to bring the total quantity of DHLW canisters stored in the repository to 6700.

In the high-flow case, the Savannah River Plant is assumed to ship 500 canisters/year over the lifetime of the repository (1998-2021). Shipments from the Hanford site will also start in 1998 and continue for ten years at a rate of 120 canisters/yr. Shipments from Idaho Falls will not start until 2007. In the first year, 300

Table 1. Defense high level waste shipments to a repository - low flow case

Years	Source (Number of canisters per year)			Total
	Savannah River	Idaho Falls	Hanford	
1998-2010	500	0 ^a	0 ^a	500
2011	200	0	0	200
Total	6700	0	0	6700

^aNo shipments from this waste generator site in the Low Flow Case.

Table 2. Defense high-level waste shipments to a repository - high flow case

Years	Source (Number of canisters per year)			Total
	Savannah River	Idaho Falls	Hanford	
1998-2006	500	0	120	620
2007	500	300	120	920
2008-2020	500	500	0	1000
2021	500	0	0	500
Total	12,000	6800	1200	20,000

Fig. 3. Movement of DHLW in Low Flow Case from SRP to Permian.

Fig. 4. Movement of DHLW in High Flow Case.

canisters will be shipped and in succeeding years (2008-2020) 500 canisters/yr will be shipped from Idaho Falls.

2.6 Estimated Transportation Distances

All truck distances shown in Table 3 were calculated with the HIGHWAY⁴ routing model. The HIGHWAY model is designed to simulate routes on the highway system in the U.S. under the conditions of interest. The data base, which contains over 240,000 miles of roadways, includes all interstates, most U.S. highways, and many roadways with state, county, or local classifications. For this study, routes that might be used for general commerce were identified. No specific

Table 3. Estimated one-way highway distances for transporting defense high level waste

Destination	Source (Distance in miles)		
	Hanford	Idaho Falls	Savannah River
Hanford	25 ^a	523	2659
Nevada Test Site	954	745	2267
Paradox	932	523	1960
Permian	1534	1107	1351
GIR	2444	1978	551

^aEstimated.

constraints reflecting any state or local restrictions applying to the shipment of radioactive materials were included in the routing criteria. Truck routes are symmetric; that is, the return trip

transporting an empty cask to a waste generation site would use the same route that was used for the loaded cask. The loaded and empty cask mileages would therefore be the same.

Rail distances, which are itemized in Table 4, were calculated using the INTERLINE⁵ railroad routing model. The INTERLINE model is designed to simulate routing on the railroad system. No specific routing constraints were imposed in this analysis. All rail shipments were assumed to travel as general freight between the origin and destination. Table 4 includes both the distance the loaded cask would be expected to travel from the waste generation site to the repository and the round trip distance (both loaded and empty shipments). In

Table 4. Estimated rail distances for transporting defense high level waste

Destination	Loaded shipments from source (miles)			Round trip distance from source (miles)		
	Hanford	Idaho Falls	Savannah River	Hanford	Idaho Falls	Savannah River
Hanford	25 ^a	692	2951	50 ^a	1384	5902
Nevada Test Site	1232	693	2739	2464	1386	5478
Paradox	1044	505	2236	2082	1004	4473
Permian	1740	1201	1581	3480	2402	3638
GIR	2689	2150	777	5379	4300	1554

^aEstimated.

general, rail routes are not symmetrical. Since the originating railroad will transport the shipment as far as possible before

transferring it to a different railroad, the loaded and return shipments can follow a different route; this fact is reflected in Table 4.

2.7 Transportation Assumptions

The defense high-level waste canisters will be transported in a heavily shielded shipping cask. The cask capacities and weights⁶ are given in Table 5.

All truck shipments were assumed to travel at an average speed of 35 mph. The average rail speed varies from about 3 mph for short

Table 5. Projected DHLW cask parameters

Mode	Capacity (canisters)	Weights (lbs)	
		Loaded	Empty
Truck	1	50,000	45,500
Rail	5	200,000	177,500

hauls to approximately 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 DHLW shipments, a total loading plus unloading time was assumed to be five days for a rail cask and three days for a truck cask. Shipping casks were assumed to be available 300 days per year.

For each transportation scenario (low-flow and high-flow), two separate transportation analyses were made for shipments to each

repository site. One analysis assumes that all shipments are made by rail and the second analysis assumes that all shipments would be made by truck.

Combining the information for the shipping rates expressed as canisters/yr in Tables 1 and 2 with the cask capacities identified in Table 5, the total number of shipments from each source can easily be calculated. This information is summarized in Table 6.

Table 6. Number of DHLW shipments from each waste generation site

Waste generation site	DHLW Shipments	
	Rail	Truck
<u>Low-Flow Case</u>		
Savannah River Plant	1340	6700
Idaho Falls	-	-
Hanford	-	-
<u>High-Flow Case</u>		
Savannah River Plant	2400	12,000
Idaho Falls	1360	6,800
Hanford	240	1,200
Total	4,000	20,000

3. TRANSPORT COSTS

3.1 Assumptions

Total transportation charges for the DHLW transportation scenarios are defined as the sum of the following three costs: (1) capital, (2) maintenance, and (3) shipping. The capital cost for purchasing the shipping casks and the annual cost for maintaining the casks were taken from Ref. 6 and are summarized in Table 7.

Table 7. Capital and maintenance costs for DHLW shipping casks

Cost	Type of cask	
	Rail	Truck
Capital (\$ 10 ⁶)	1.8	1.1
Maintenance (\$ 10 ⁶ /cask-year)	0.09	0.06

The estimated round trip shipping costs for transporting DHLW canisters by truck are summarized in Table 8. It was assumed that DOE will be making the shipments utilizing a two-driver team which will be required to report their position every 90 min. No other special security personnel or escort vehicles are required. The costs in Table 8 include the extra driver and the additional expenses incurred by making periodic position reports (reduces average speed).⁷

Table 8. Estimated truck costs for transporting DHLW canisters^a

Destination	Cost from source (\$/shipment)		
	Hanford	Idaho Falls	Savannah River
Hanford	b	1610	7790
Nevada Test Site	3890	1930	6340
Paradox	2820	1570	6120
Permian	4600	2460	2840
GIR	7020	5530	1340

^aRound trip costs, includes charges for extra driver and periodic reporting of location.

^bShipment on DOE reservation, shipping cost assumed to be included in facility operating cost.

Shipments of DHLW canisters generated at Hanford to a Basalt repository at Hanford present a special problem. Actual locations of the facilities are not known. It was assumed that a round trip distance of approximately 50 miles would be required. However, it is also assumed that private carriers would not be used to make these shipments, hence no shipping charges are assigned to this origin-destination pair. The turnaround times for loading and unloading the cask still apply.

Costs for shipping high-level waste canisters by rail proved to be difficult to ascertain. Only a limited number of current rail rates that were requested were received from the railroads serving the source locations. As a result, these new costs were compared with a correlation developed in 1981 for the shipment of spent fuel.¹⁵ The

new cost data were well represented by the correlation after applying an escalation factor of 8%. This revised correlation was used to estimate the costs for each source-destination pair. The results are given in Table 9.

These rates reflect the assumption that the casks would be handled as a hazardous cargo, and that neither special trains nor escort personnel would be required during the shipment.

3.2 Results

Table 6 presents the number of shipments required from each site for both the low-flow and high-flow case. When these numbers are applied to the shipping distances identified in Tables 3 and 4, the total number of miles traveled over the entire storage campaign can be determined. The distances calculated for shipping DHLW canisters by truck are shown in Table 10 for the low-flow case and Table 11 for the

Table 9. Estimated rail costs^a for transporting DHLW canisters

Destination	Rail costs from source (\$/CWT)		
	Savannah River	Idaho	Hanford
Hanford	17.37	6.75	b
NTS	16.21	6.73	10.08
Paradox	13.51	5.70	8.51
Permian	10.81	9.35	11.96
GIR	6.48	13.37	16.21

^aRail tariffs are normally given as dollars per hundredweight (\$/CWT).

^bOn-site shipment, no charge assigned for transporting waste canisters from waste processing facility to repository site.

high-flow case. The corresponding distances for rail shipments are shown in Tables 12 and 13, respectively.

The total number of casks required for each case studied is a function of the shipping distance, transportation speed, the days required to load and unload the cask (the total turnaround time), and the number of canisters transported per trip.

Table 10. Total truck transport distances - low-flow case

Destination	Distance from source (10 ⁶ miles)	
	Savannah River	
Hanford	35.63	
NTS	30.38	
Paradox	26.26	
Permian	18.10	
GIR	7.38	

Table 11. Total truck transport distances - high-flow case

Destination	Distance from source (10 ⁶ miles)			
	Savannah River	Idaho	Hanford	Total
Hanford	63.82	7.11	0.06 ^a	70.99
NTS	54.41	10.13	2.29	66.83
Paradox	47.04	7.11	2.24	56.39
Permian	32.42	15.06	3.68	51.16
GIR	13.22	26.90	5.87	45.99

^aOn-site shipment.

Table 12. Total rail transport distances — low-flow case

Destination	Distance from source (10 ⁶ miles)
	Savannah River
Hanford	7.91
NTS	7.34
Paradox	5.99
Permian	4.88
GIR	2.08

Table 13. Total rail transport distances — high-flow case

Destination	Distance from source (10 ⁶ miles)			
	Savannah River	Idaho	Hanford	Total
Hanford	14.16	1.88	0.01 ^a	16.05
NTS	13.15	1.89	0.59	15.63
Paradox	10.74	1.36	0.50	12.60
Permian	8.73	3.27	0.84	12.84
GIR	3.73	5.85	1.29	10.87

^aOn-site shipment.

Each cask, operating for 300 days per year, will be capable of transporting a specific number of canisters from each source to a given destination. The maximum number of casks required over the entire campaign has been calculated for each source-destination pair and for each shipping scenario; the results are presented in Tables 14-17.

It is important to note that for the high-flow case, the number of shipments vary as a function of year and source (see Table 2). Because of this, some of the casks used to transport DHLW from Hanford between 1998-2007 can be used in transporting DHLW from Idaho Falls after the year 2007. As a result, the total cask fleet requirements shown in Tables 15 and 17 are not the sum of the individual cask fleet requirements specified for the three sources.

Table 14. Truck cask fleet requirements - low-flow case

Destination	No. of casks required Savannah River
Hanford	16
NTS	14
Paradox	13
Permian	11
GIR	8

Table 15. Truck cask fleet requirements — high-flow case

Destination	No. of casks required			Total ^a
	Savannah River	Idaho	Hanford	
Hanford	16	8	2	24
NTS	14	8	3	22
Paradox	13	8	3	21
Permian	11	10	3	21
GIR	8	13	4	21

^aCasks used to transport HLW from Hanford, WA between 1998-2007 are used to make up part of the cask fleet requirement for shipments leaving Idaho Falls 2008-2020.

Table 16. Rail cask fleet requirements — low-flow case

Destination	No. of casks required Savannah River
Hanford	11
NTS	11
Paradox	10
Permian	10
GIR	7

As noted in Sect. 3.1, the total transportation charges are made up of shipping, maintenance, and capital (or cask purchase) costs. Combining the information on shipping costs per round trip by truck given in Table 8 with the number of trips identified in Table 6 over the appropriate campaign allows one to calculate the total

transportation costs for truck shipments. These results are reported in Tables 18 and 19 for the low- and high-flow cases, respectively. The maintenance and capital costs of the truck casks, derived from Table 7 and the cask fleet requirements identified in Tables 14 and 15, are also included in Tables 18 and 19.

Table 17. Rail cask fleet requirements - high-flow case

Destination	No. of casks required			
	Savannah River	Idaho	Hanford	Total ^a
Hanford	11	7	1	18
NTS	11	7	2	18
Paradox	10	6	2	16
Permian	10	8	3	18
GIR	7	10	3	17

^aSeveral casks used to transport HLW from Hanford, WA between 1998-2007 are also used to make up part of the cask fleet requirement for shipments leaving Idaho Falls 2008-2020.

Table 18. Total truck transportation costs - low-flow case^a

Type of cost	Total costs for destination (\$10 ⁶)				
	Hanford	NTS	Paradox	Permian	GIR
Shipping	52.18	42.49	40.98	18.99	9.00
Cask maintenance	12.90	11.28	10.50	8.88	6.42
Cask purchase	<u>17.60</u>	<u>15.40</u>	<u>14.30</u>	<u>12.10</u>	<u>8.80</u>
Total	82.68	69.17	65.78	39.97	24.22

^aSource is the Savannah River Plant.

Table 19. Total truck transportation costs — high-flow case^a

Type of cost	Total costs for destination (\$10 ⁶)				
	Hanford	NTS	Paradox	Permian	GIR
Shipping	104.41	94.87	87.45	56.24	62.17
Cask maintenance	30.78	28.50	27.06	25.80	24.54
Cask purchase	<u>26.40</u>	<u>24.20</u>	<u>23.10</u>	<u>23.10</u>	<u>23.10</u>
Total	161.59	147.57	137.61	105.14	109.81

^aFrom sources located at the Savannah River Plant, Idaho Falls, and Hanford.

The cost of rail shipments are calculated differently than truck shipments because the cost data were obtained from the railroads in \$/hundredweight (or \$/CWT). Combining the rates identified in Table 9 with the loaded and empty rail cask weights shown in Table 5 and the number of round trips given in Table 6 allows one to calculate the total shipping costs for rail transport. These results are reported in Tables 20 and 21 for the low- and high-flow cases, respectively. Also included in these tables are the maintenance and capital costs of the rail casks.

Table 20. Total rail transportation costs — low-flow case^a

Type of cost	Total costs for destination (\$10 ⁶)				
	Hanford	NTS	Paradox	Permian	GIR
Shipping	87.89	82.00	68.34	54.68	32.79
Cask maintenance	13.22	13.22	12.06	12.06	8.46
Cask purchase	<u>19.80</u>	<u>19.80</u>	<u>18.00</u>	<u>18.00</u>	<u>12.60</u>
Total	120.91	115.02	98.40	84.74	53.85

^aSource is the Savannah River Plant.

Table 21. Total rail transportation costs — high-flow case^a

Cost	Total costs for destination (\$10 ⁶)				
	Hanford	NTS	Paradox	Permian	GIR
Shipping	192.03	190.56	159.37	156.78	142.04
Cask maintenance	33.21	34.11	30.78	34.11	30.06
Cask purchase	<u>32.04</u>	<u>32.04</u>	<u>28.80</u>	<u>32.40</u>	<u>30.60</u>
Total	257.28	256.71	218.95	223.29	202.70

^aFrom sources located at the Savannah River Plant, Idaho Falls, and Hanford.

4. RISK ANALYSIS

Risks and impacts have been estimated in this report using the same methods and assumptions described and documented in Ref. 6. The assumptions and values of various factors used in the calculations are given in this report, but the reader is referred to Ref. 6 for detailed explanations. The assumptions used in both reports are intended to be consistent with the Nuclear Waste Terminal Storage Program and are consistent with past transportation risk studies performed by the Transportation Technology Center at Sandia National Laboratories, Albuquerque, New Mexico.

4.1 Radiological Impacts

The total radiological impact is the sum of the impact to occupational workers and the general population exposed under normal and accident conditions. The impacts are different for truck and rail transportation modes and are a function of the distance traveled and the population that is exposed as the shipment passes by. Federal regulations require both rail and truck casks be limited to a dose rate of 10 mrem/h at 2 m from the accessible surface.¹¹ For a given cask design, the actual dose rate will depend upon the age of the fuel.⁹ For this report, the radioactivity contained in a canister was assumed to average 1.5×10^5 Ci/canister.¹⁰

A truck cask contains one canister and consequently the number of truck shipments equals the number of canisters to be shipped. A rail cask contains five canisters; therefore the number of rail shipments is equivalent to 1/5 the number of canisters to be shipped.

The amount of risk to which the public is exposed depends on accident rates (probability of an accident per mile of travel), the quantity of activity involved (assumed to average 1.5×10^5 Ci/canister), and the severity of the accident. The severity of the accident will determine how much exposure results from the accident; exposure will be a function of how much radioactivity, if any, escapes from the canister.

However, a significant amount of research and development has gone into the design and manufacture of both truck and rail transportation containers to insure that they will survive extremely severe accidents without serious consequences. The probability that release of material will occur is very small. If release should occur, experimental evidence indicates that the radiological consequences would not be great.¹⁴

It is assumed that in transporting the canisters from source to repository that 80% of the distance traveled is in rural areas (mean population density 15.5 persons/mi²), 19% of the distance is in suburban areas (mean population density 1840 persons/mi²), and 1% of the distance is in urban areas (mean population density 10,000 persons/mi²).¹² Radiological unit factors which took these parameters into account were used in calculating the population dose received as the canisters were passing along the route. The unit factors are

given in person-rem of exposure per mile of travel. The expected amount of time a shipment stops in transit and the velocity during travel in each population density zone were used in determining the unit factors. The unit factors, which are different for each zone and mode of transportation, are presented in Table 22.

Table 22. Radiological unit factors (in person-rem/mile) for truck and rail travel^a

	Truck			Rail		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal						
Occupational	4.2E-05	9.2E-05	1.5E-04	6.4E-07	6.4E-07	6.4E-07
Nonoccupational	2.1E-04	3.4E-04	4.2E-04	3.4E-03	3.4E-03	3.4E-03
Accident	7.9E-10	1.2E-06	4.2E-06	2.4E-09	5.1E-06	8.4E-05

^aValues derived from Tables 20 and 21, SAND83-0867.⁵

The occupational term in Table 22 refers to those people that are exposed to radiation from a cask as a result of their occupation, such as truck drivers or members of a train crew. The public is considered the nonoccupational group.

The factor that was used to convert equivalent whole body population dose to latent cancers (in this and future generations) was 2×10^{-4} latent cancers per person-rem of exposure.¹³

4.1.1 High-Flow Case

Table 23 contains the calculated values of radiological impacts of transporting high-level defense waste from three sources to five

Table 23. Radiological impacts (in latent cancer fatalities)
for 24-year campaign - high-flow case

	Destination				
	GIR	Permian	Paradox	NTS	Hanford
<u>Truck</u>					
Normal					
Occupational	0.2	0.3	0.3	0.3	0.4
Nonoccupational	1.1	1.2	1.3	1.6	1.7
Accident					
Nonoccupational	0.001	0.001	0.001	0.002	0.004
Total	1.3	1.5	1.6	1.9	2.1
<u>Rail</u>					
Normal					
Occupational	<0.001	<0.001	<0.001	0.001	0.001
Nonoccupational	3.7	3.9	4.3	5.3	5.4
Accident					
Nonoccupational	0.002	0.002	0.002	0.003	0.003
Total	3.7	3.9	4.3	5.3	5.4

candidate repository sites. The results indicate the following: (1) the projected impacts are small compared to risks already existing in daily life; (2) the impacts are clearly a function of the distance traveled; (3) rail transport has greater radiological impact than truck transport; and (4) accidents contribute a very small part of the total impact. Rail impacts are greater than truck impacts because rail distances are generally longer, trains travel slower than trucks, and trains stop for longer periods of time. It is also apparent that there will be no difference in the risk of transporting DHLW to a defense-only repository or to a combined defense-commercial repository as long as either repository were located at the same site.

4.1.2 Low-Flow Case

It is assumed in the low-flow case that only Savannah River will ship canisters to a repository. The radiological impacts from transporting these canisters from Savannah River to the five candidate repository sites are given in Table 24.

The impacts vary between sites by factors directly proportional to distance. Impacts of the GIR site (the closest repository to Savannah River) and the Hanford site (the most distant repository from Savannah River) vary by factors of 4.7 for truck transport and 3.8 for rail transport. The impacts occur mostly to the public from both modes of transport, with the rail mode showing a greater impact than the truck mode by roughly a factor of 3. Accidents contribute very little to the total impact.

Table 24. Radiological impacts (in latent cancer fatalities)
for the low-flow case

	Destination				
	GIR	Permian	Paradox	NTS	Hanford
<u>Truck</u>					
Normal					
Occupational	0.04	0.09	0.1	0.2	0.2
Nonoccupational	0.2	0.4	0.6	0.7	0.8
Accident					
Nonoccupational	<0.001	<0.001	<0.001	<0.001	<0.001
Total	0.2	0.5	0.7	0.9	1.0
<u>Rail</u>					
Normal					
Occupational	<0.001	<0.001	<0.001	<0.001	<0.001
Nonoccupational	0.7	1.4	2.0	2.5	2.7
Accident					
Nonoccupational	<0.001	<0.001	<0.001	<0.001	<0.001
Total	0.7	1.4	2.0	2.5	2.7

4.2 Nonradiological Impacts

Nonradiological impacts were estimated using unit risk factors (deaths or injuries per mile of travel) presented in Table 25. The factors are categorized according to normal and accident conditions of transport for truck and rail modes. The normal factors are for the general public in urban areas (factors for suburban and rural areas are much lower and contribute very little to the total) and are given as latent cancer fatalities per mile, which result from the carcinogenic emissions from diesel engines. Accident factors are given separately for occupational workers and the public in terms of fatalities and injuries.

4.2.1 High-Flow Case

By applying the total distance traveled to the appropriate factors in Table 25, the nonradiological impacts were calculated and values for the high flow case are given in Table 26. Accidents, resulting in fatalities and injuries, account for nearly all of the nonradiological impacts. The number of fatalities is greater for truck transport than for rail transport by a factor of about 13. In truck accidents, the public sustains about 78% of the fatalities and 95% of the injuries with the truck drivers sustaining the other 22% of the deaths and 5% of the injuries. In rail accidents, the public receives about 90% of the fatalities and 15% of the injuries with occupational workers receiving the remainder.

Table 25. Nonradiological unit factors for truck and rail travel^a

	Truck			Rail		
	Rural	Suburban	Urban	Rural	Suburban	Urban
Normal						
Nonoccupational						
(latent cancers/mile) -	-	-	1.6E-7	-	-	2.1E-7
Accident						
Nonoccupational						
Fatalities/mile	8.5E-8	2.1E-8	1.2E-8	2.7E-8	2.7E-8	2.7E-8
Injuries/mile	1.3E-6	6.1E-7	6.0E-7	5.3E-8	5.3E-8	5.3E-8
Occupational						
Fatalities/mile	2.4E-8	6.0E-9	3.4E-9	2.3E-9	2.3E-9	2.3E-9
Injuries/mile	4.5E-8	2.1E-8	2.1E-8	3.1E-7	3.1E-7	3.1E-7

^aValues derived from Table 22, SAND83-0867.5

Table 26. Nonradiological impacts (deaths and injuries for 24-yr campaign) - high-flow case

	Destination				
	GIR	Permian	Paradox	NTS	Hanford
<u>Truck</u>					
Normal (latent cancer fatalities)					
Nonoccupational	0.07	0.08	0.09	0.1	0.1
Accidents (fatalities)					
Occupational	0.9	1.0	1.2	1.4	1.4
Nonoccupational	<u>3.3</u>	<u>3.7</u>	<u>4.1</u>	<u>4.8</u>	<u>5.0</u>
Total	4.3	4.8	5.4	6.3	6.5
Accidents (injuries)					
Occupational	1.8	2.1	2.3	2.7	2.8
Nonoccupational	<u>53</u>	<u>59</u>	<u>65</u>	<u>77</u>	<u>80</u>
Total	55	61	67	80	83
<u>Rail</u>					
Normal (latent cancer fatalities)					
Nonoccupational	0.02	0.03	0.03	0.03	0.03
Accidents (fatalities)					
Occupational	0.02	0.03	0.03	0.04	0.04
Nonoccupational	<u>0.3</u>	<u>0.4</u>	<u>0.3</u>	<u>0.4</u>	<u>0.4</u>
Total	0.3	0.5	0.4	0.5	0.5
Accidents (injuries)					
Occupational	3.3	3.9	3.9	4.8	4.9
Nonoccupational	<u>0.6</u>	<u>0.7</u>	<u>0.7</u>	<u>0.8</u>	<u>0.9</u>
Total	4	5	5	6	6

The maximum number of deaths postulated over the 24-year campaign is about six for trucks using the Hanford site and about 0.5 for rail transport to the Hanford site. This is very small compared with the truck and rail fatalities expected in the United States for this same period. In 1980 there were 2528 truck fatalities and 1242 rail fatalities; at this rate there would be about 61,000 truck fatalities and 30,000 rail fatalities in a 24-year period.

Impacts are linearly related to the total shipment distance which results in the Hanford repository site showing the greatest impact. However, impacts for the Hanford site are only about 1.5 times those for the GIR site, which requires the least total distance of travel.

4.2.2 Low-Flow Case

Nonradiological impacts for the low-flow case are presented in Table 27. As expected, impacts vary with the total distance traveled as was shown in the radiological case. Savannah River being closer to the GIR site than the Hanford site results in a much lower impact.

A comparison of the high-flow and low-flow cases shows that repository location is a much more important parameter in the low-flow case. In both the high-flow and low-flow cases, most of the impacts (about 90% and 100%, respectively) involving shipments to the Hanford repository site are associated with shipments from Savannah River. Both Idaho Falls and Hanford sources, being located much closer to the Hanford repository site, contribute little to the high-flow case total.

Table 27. Nonradiological impacts for the low-flow case

	Destination				
	GIR	Permian	Paradox	NTS	Hanford
<u>Truck</u>					
Normal (latent cancer fatalities)					
Nonoccupational	0.01	0.03	0.04	0.05	0.06
Accidents (fatalities)					
Occupational	0.2	0.4	0.5	0.6	0.7
Nonoccupational	<u>0.5</u>	<u>1.3</u>	<u>1.9</u>	<u>2.2</u>	<u>2.5</u>
Total fatalities	0.7	1.7	2.4	2.9	3.3
Accidents (injuries)					
Occupational	0.3	0.7	1.1	1.2	1.4
Nonoccupational	<u>9</u>	<u>21</u>	<u>30</u>	<u>35</u>	<u>40</u>
Total injuries	9	22	31	36	41
<u>Rail</u>					
Normal (latent cancer fatalities)					
Nonoccupational	0.004	0.01	0.01	0.02	0.02
Accidents (fatalities)					
Occupational	0.005	0.01	0.01	0.02	0.02
Nonoccupational	<u>0.06</u>	<u>0.1</u>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>
Total fatalities	0.07	0.1	0.2	0.2	0.2
Accidents (injuries)					
Occupational	0.6	1.5	1.8	2.2	2.4
Nonoccupational	<u>0.1</u>	<u>0.3</u>	<u>0.3</u>	<u>0.4</u>	<u>0.4</u>
Total injuries	0.7	1.8	2.1	2.6	2.8

4.3 Maximum Individual Exposure

The individual receiving the maximum radiation exposure is assumed to live 100 ft from the highway or railway which carries all the defense high-level waste to a repository with the trucks or trains passing his house at 15 mph. The total exposure to such an individual is discussed in Ref. 15. The cumulative dose received by an individual during the passage of 20,000 canisters of high-level waste is estimated to be 15 mrem for the truck mode and about 3 mrem for the rail mode. If it is assumed that background radiation is 100 mrem per year, then in 24 years, the cumulative dose to the same individual from background would be 2.4×10^3 mrem. As a result, this individual would receive an increased exposure of 0.6% assuming truck shipments, or 0.1% if rail shipments are used when compared to normal background over the same period.

4.4 Maximum Credible Radiological Accident

The design criteria for radioactive materials transportation packages have been chosen so that the public will be protected under extremely severe accident conditions. There have been no radiological releases involving packages designed to the same criteria as the packages considered in this analysis. Experimental evidence combined with conservative (worst case) assumptions using spent fuel indicated that only one delayed fatality would result from an accident more severe than the most credible accident.¹³ Because the form of the

defense high-level waste is even less likely to result in significant dispersal than spent fuel, it is concluded that no consequences greater than that predicted for spent fuel would be expected for the most credible radiological accident involving defense high-level waste.

4.5 Uncertainties in Risk Calculations

The radiological and nonradiological risk calculations in this report have different uncertainties associated with them. Most of the parameters used in the nonradiological calculations are based on documented accident reports and thus are quite reliable; nevertheless, the results may vary by a factor of 2 higher or lower. Lacking adequate historical data on the radiological risk factors, the radiological risk analyses were based on conservative engineering judgement which results in higher uncertainty. Generally, these conservative values were used throughout so that radiological results are probably upper limits and may be high by as much as one or two orders of magnitude.¹³

All sites were assessed in the same manner so that the same uncertainty is present in all the results. However, the results may be reliably used for comparative purposes between the potential repository sites.

4.6 Risks from a Mix of Shipment Modes

The risk assessments in Sects. 4.1 and 4.2 were performed assuming shipments were either totally by truck or totally by rail.

In practice, shipments may be partly by truck and partly by rail. To assess the risk of shipping by a given mix of transport modes, the fraction from each mode may be applied to the appropriate numbers given in Tables 23-27 and then may be added together to give the total impacts. For example, if x is the fraction by truck, then $1-x$ is the fraction by rail and the sum of the two individual impacts gives the total impact.

5. CONCLUSIONS

In 1998 the first canisters of high level waste are schedule to move from one or more of the three sites identified in Fig. 1 to a repository located in one of the five sites identified in Fig. 2. The material will be shipped either by truck or by rail. Rail shipments are frequently preferred from an operational point of view because rail casks can carry significantly more material in them than truck casks. It is often easier to handle one rail cask than five truck casks containing the same total number of canisters.

Current regulations identify the interstate system as the preferred network for truck shipments. There are no comparable requirements for rail shipments. However, there are still options available in determining the railroads that would handle the shipments between any two shipping-receiving points. While a shortest path could be used, it might not be the fastest, nor the "best" route from other operating considerations. Almost certainly both rail and truck shipments will move over several different routes between any two

widely separated source-destination points. The total cost and total risk will be essentially the same regardless of the routes used.

5.1 Effects of Repository Location

The potential location of a repository site varies from a south central area (the Gulf Interior Region) to a northwestern area (the Hanford reservation). As a result, the total shipping distances can vary by a factor of from 4.8 (for truck shipments in the low-flow case) to 1.48 (for rail shipments in the high-flow case). Since shipping cost and cask fleet requirements are strongly influenced by the total distance traveled and vehicle speed, the chosen repository location will have a significant effect on the total transportation charges. However, once the repository site is picked, there will be no difference in costs in shipping to a defense-only or a combined defense-commercial repository.

The only possible exception might occur if the receiving facilities of the combined repository gets overloaded with cask receipts from commercial shippers, influencing (a) the number of defense shipments that could be received per unit time or (b) the mode used for defense shipments. It is therefore important that the design of the receiving facilities be adequately sized to prevent this type of interaction.

The total risks associated with shipping high level waste to a repository are also strongly influenced by the total distance

traveled. So while there is a variation in risk when comparing one repository site against another, once the site is chosen, there will be no difference in the risk of transportation as a function of repository type.

5.2 Results of Risk Analysis

In addition, the general observations given in Ref. 6 would hold irrespective of which site is chosen. For radiological risks these observations are:

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 to a very small portion of the total radiological impact,
4. The exposure to the public at relief stops dominates the radiological impact, and
5. The results are clearly a function of the distance traveled.

For nonradiological risks, these are:

1. Impacts increase linearly with distance traveled,
2. The public are subject to the greatest impact,
3. The impacts are small relative to those of general commerce.

5.3 Effects of Transport Mode

The mode of transport will have a significant effect on the total transportation costs. Rail will be more expensive irregardless of the repository location. For the low-flow case, total rail costs vary from \$53.85 million for shipments to a GIR repository to \$120.91 million if Hanford is the destination (see Table 20). These values may be compared to truck costs which vary from \$24.22 million for a GIR destination to \$82.68 million if the repository is located at Hanford (see Table 18). For the high-flow case, the costs vary from \$202.70 million to \$257.28 million for rail; for truck the costs vary from \$109.81 million to \$161.59 million.

The effect of transport mode on risk can be determined by examining the tables in Sect. 4. With regard to radiological impacts, high-flow case, latent cancers predicted for rail shipments vary from 3.7 to 5.4 depending upon the destination over the 24-year campaign. These figures may be compared to values that vary from 1.3 to 2.1 for truck under the same conditions (see Table 23). For the low-flow case, latent cancer fatalities should vary from 0.7 to 2.7 for rail; again, depending upon the destination, these figures may be compared to a range of 0.2 to 1.0 for truck under the same conditions (see Table 24). These higher dose commitments for rail reflect the fact that the average speed of the train is assumed to be much lower than for truck, and the train may spend some time sitting in rail yards. The advantage of fewer rail shipments is not sufficient to offset this lower speed.

With regard to nonradiological impacts, both injuries and fatalities are higher by an order of magnitude when truck is the transport mode used than if rail is used (see Table 26). This reflects the higher accident rates for trucks (see Table 25) and the much larger number of shipments required if truck is the mode used.

This study conservatively assumed that the dose rate 2m from the accessible cask surface was 10 mrem/h during shipment. This is the maximum limit permitted in the regulations. However, it is possible that the repository operators may lower the maximum dose rate in order to reduce the dose commitments to workers that receive and unload the casks. Such a reduction would have the effect of increasing the cask weight or changing the cask shielding to a material having a higher density (e.g., depleted uranium). Given that the canister is a fixed and standard size, it would not be convenient to reduce the payload to achieve a lower dose rate. The above changes to the cask, aimed at reducing personnel exposure, would result in higher shipping costs (if additional weight were added) or capital costs (if depleted uranium were employed as the primary shielding material).

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