A PRELIMINARY ANALYSIS OF THE RISK OF TRANSPORTING NUCLEAR WASTE TO POTENTIAL CANDIDATE COMMERCIAL REPOSITORY SITES

Marcella M. Madsen
Sandia National Laboratories*
Albuquerque, New Mexico 87185

ABSTRACT

In accordance with the provisions of the Nuclear Waste Policy Act of 1982, environmental assessments for potential candidate sites are required to provide a basis for selection of the first site for disposal of commercial radioactive waste in deep geologic repositories. A preliminary analysis of the impacts of transportation for each of the five potential sites will be described. Transportation was assumed to be entirely by truck or entirely by rail in order to obtain bounding impacts. This paper will present both radiological and nonradiological risks for the once-through fuel cycle.

INTRODUCTION

Environmental assessments are required by the Nuclear Waste Policy Act of 1982 (Public Law 97-425) to support site characterization nominations for the nation's first commercial high-level nuclear waste repository. One of the elements requiring appraisal in these assessments is transportation. This preliminary analysis of the risk of transporting nuclear waste to potential candidate commercial repository sites[1] will form the foundation for the transportation evaluation. It is envisioned this examination of transportation risk will be a first step in an iterative process that will identify key risk elements and related parameters. Values for these risks and parameters will be refined prior to the preparation of environmental impact statements.

In this analysis, a hypothetical repository with an operating period of 26 years was assumed to be located at each of the five potential candidate sites. These locations, shown in Fig. 1, are: Gulf Interior Region (domed salt), Permian Basin (bedded salt), Paradox Basin (bedded salt), Yucca Mountain (tuff), and Hanford Reservation (basalt). (The Gulf Interior Region will be referred to as GIR.) In order to obtain bounding impacts, transportation was assumed to be entirely by truck or entirely by rail.

Two fuel-cycle scenarios were considered in the analysis: once-through and reprocessing. However, this paper will describe only the once-through fuel cycle scenario in which spent fuel from the commercial nuclear industry was transported directly from the reactors to the repository. Defense high-level waste (DHLW) from the Savannah River Plant and high-level waste from the West Valley Reprocessing Plant (WVHLW) was also included in the analysis. The West Valley waste was generated by both the commercial and defense sectors. The repository capacity was assumed to be 72,000 tonnes of heavy metal (tHM) in spent fuel, 6,720 canisters of DHLW, and 300 canisters of WVHLW. This capacity is slightly higher than the 70,000 tHM total specified in the Nuclear Waste Policy Act because much of the analysis was completed prior to the time the Act was signed into law. A schematic detailing origins and destinations of shipments is shown in Fig. 2.

Fig. 1. Key Locations in Repository Transportation Assessment

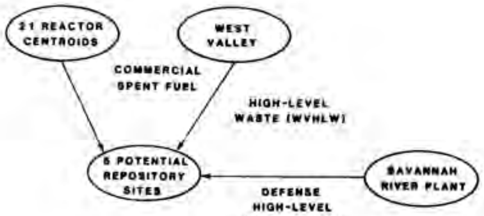

Fig. 2. Once-through Fuel Cycle Scenario

---

*In support of the United States Department of Energy under Contract DE-AC04-76DP00789

RISK ANALYSIS

Transport risks for radioactive waste shipments can be categorized as radiological and nonradiological. For both categories the impacts due to accidents and those due to accident-free transport were considered. The evaluation of the radiological accident-free component involves a determination of the direct external radiation dose emitted by the radioactive material packages as a shipment passes by or while it is stopped. An estimate of the radioactive material that might be released in an accident and the resultant health effects were considered for the radiological accident category. The health effects from the pollutants generated by burning diesel fuel to move the shipment is the measure of the nonradiological effects of accident-free transportation. Deaths and injuries resulting from traffic accidents comprise the nonradiological accident impacts.

Unit factors that quantify the risk of the shipment traveling a distance of one kilometer were calculated for each radiological and nonradiological risk category. These unit factors were calculated for each of three population zones: urban, suburban, and rural. The products of the number of shipments, distance per shipment, percentage of travel in each population zone, and unit factors were summed over population zones, waste types, and risk categories to obtain total impacts. Methods for calculating each of the terms will be described in the following sections.

RADIOLOGICAL UNIT FACTORS

A computer code, RADTRAN II, used to combine the large set of parameters necessary to calculate the radiological unit factors, will be briefly described. Derivations of all equations are discussed in Reference 2 and use of the code is detailed in Reference 3.

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

The normal impacts to the occupationally exposed population were calculated by the crew model. Numbers of crewmen, distances between the shipment and the crew compartment, transport index (exposure rate term defined by regulations), package dimension, and velocity were required input for the truck-mode. Because of the large amounts of shielding and the large source-to-crew distances, the rail crew doses were 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 was included in the model.

Fig. 3. Accident-free Population Dose Models

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

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

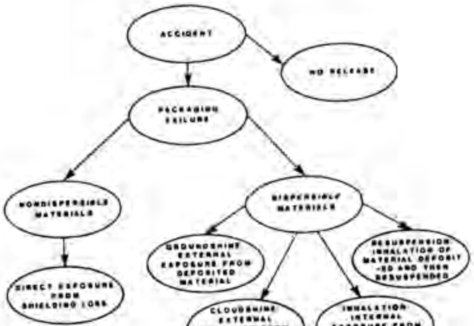

Fig. 4. Accident Dose Pathways

Since a detailed radionuclide inventory for boiling-water-reactor (BWR) spent fuel was not available from sponsors of the study, only pressurized-water-reactor (PWR) spent fuel was analyzed. It was assumed, on a basis of a tonne of heavy metal in the spent fuel, the radionuclide inventory for BWR spent fuel was the same as PWR spent fuel. The spent fuel was assumed to be 10 years old and to contain 0.46 tHM/fuel assembly. To ensure safe transport, casks designed to meet NRC/DOT requirements were assumed to be used for shipment. Table I describes the transport index (TI), container sizes, and number of containers per shipment.

TABLE I

Container Description

Waste	Container	Size	TI	Containers/Package Truck	 Rail
Spent Fuel	Assemblies	PWR/BWR*	20	2/5	12/32
DHLW	Canister	0.60 x 3.0 m	20	1	5
WVHLW	Canister	0.60 x 3.0 m	20	1	7

*Pressurized-Water-Reactor/Boiling-Water-Reactor

Key parameters in this analysis include the amount of time a shipment stops during transit and the health-effects conversion factor. For truck transport 0.011 hours of stop time per km of travel was used and 0.086 hours of stop time per km of travel was used for rail. A value of 2×10^{-4} latent cancers per person-rem (present and future generations) was used to convert equivalent whole-body dose to latent cancer fatalities.

NONRADIOLOGICAL UNIT FACTORS

Statistical data were used to compile nonradiological unit factors. Accident-free unit-risk factors were based on effects from pollutants.[4] These factors have only been specified for urban regions. The injury and fatality rates for truck transport were obtained from References 5 and 6. In order to determine rail unit factors, railcar miles given in Reference 7 and fatalities and injuries recorded in Reference 8 were used.

DISTANCE PER SHIPMENT

For spent fuel shipments, a simplifying assumption was made to replace the approximately 80 actual reactor origins with 21 centroid locations. All of the reactors in each National Electric Reliability Council (NERC) region were identified. Each region was divided into subregions based upon geographic location of the reactors. The geographic centroid of each subregion was calculated and the nearest node recorded in the highway and rail routing models (HIGHWAY[9] and INTERLINE[10]) was selected as the centroid. Table II contains the total one-way distance traveled to each site during 26 years of repository operation.

NUMBER OF SHIPMENTS

The number of shipments of spent fuel was based on the need to maintain a full-core reserve at each reactor storage pool. Individual reactor discharges and storage pool capacity were obtained from Reference 11. It was assumed that all casks shipped would be fully loaded. Table III shows the number of shipments required for 26 years of repository operation.

FRACTION OF TRAVEL IN POPULATION ZONES

The population densities of the regions across which shipments must be moved to reach a repository site influence overall risk. To calculate the fractions of travel in rural, suburban, and urban regions, 1980 population density counts were used. A population density data base was contoured and combined with possible transportation routes from sources to repositories. Distances that each route traversed each of the population density zones were then accumulated. Average percentages were calculated for each repository site and are shown in Table IV.

TABLE II

Total Distances of Shipment for 26-Year Operating Period (Million Kilometers)*

	Spent Fuel	DHLW	WVHLW	TOTAL
100% Truck				
GIR	130	6	0.5	140**
Permian	180	15	0.8	190
Paradox	220	21	0.9	250
Yucca Mt.	270	24	1	300
Hanford	290	29	1	320
100% Rail				
GIR	26	2	0.1	28
Permian	32	3	0.1	35
Paradox	40	5	0.1	45
Yucca Mt.	49	6	0.2	55
Hanford	51	6	0.2	58

---

*One-way shipping distances

**Rows may not total due to rounding to two significant figures

TABLE III

Number of Shipments Required for 26 Years of Repository Operation

Waste Type	100% Shipments By Rail	100% Shipments By Truck
Spent Fuel	13,415	82,469
DHLW	1,344	6,720
WVHLW	43	300

TABLE IV

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

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

---

*Rural corresponds to 6 people/km^2 (mean density)
Suburban corresponds to 719 people/km^2 (mean density)
Urban corresponds to 3,861 people/km^2 (mean density)

RADIOLOGICAL IMPACTS

Table V contains the calculated values for radiological impacts of 26 years of transportation to each of five sites. The occupational category includes truck drivers and railroad inspectors. The public is the non-occupationally exposed group. An inspection of detailed radiological impact evaluations indicates the largest contribution to radiological impacts is from the stops model. An examination of the impacts shows that:

1. Accidents provide a very small contribution to the total radiological impacts.
2. Impacts are a function of the distance traveled.
3. The public exposure at stops dominates the impacts.

TABLE V

Radiological Impacts (Latent Cancer Fatalities for 26 Year Operating Period)

	Repository Location				
	GIR	Permian	Paradox	Yucca Mt.	Hanford
100% Truck					
Accident-free					
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
100% Rail					
Accident-free					
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

Although a factor of 2 difference is noted between the truck and rail modes, caution must be exercised in making judgments about the relative safety of the two modes because of uncertainties in the analysis. Conservative values have been used in this analysis; therefore, results are probably upper limits. As uncertainties are reduced, impacts could be reduced by one or two orders of magnitude. A critical examination of salient parameters such as the stop parameters is under way.

To place the impacts in perspective, the health-effects conversion factor can be applied to the natural background radiation dose received by the United States population. If it is assumed that each person is exposed to an annual dose of 100 millirem the number of latent cancer fatalities from background radiation sources would be 117,000 for the 26 years of repository transportation. The largest radiological impact for 26 years is 26 latent cancer fatalities.

NONRADIOLOGICAL IMPACTS

Values for nonradiological impacts of transport by truck and rail are shown in Table VI. These evaluations included round trip distances to take into account return trips with empty cars. An inspection of the impacts suggests that:

1. Numbers of nonradiological fatalities from truck accidents are significantly greater than rail.
2. The dominant nonradiological impact is from accidents.
3. The impacts increase linearly with the distance traveled.

Since most of the parameters used to calculate nonradiological accident risk are based on a large base of accident statistics, the uncertainty is lower than that associated with radiological risk. These risks might be expected to vary by a factor of two higher or lower. A perspective of these values can be obtained by reviewing the 1980 accident statistics. In this year, truck accidents resulted in 2,528 fatalities and rail transport resulted in 1,242 fatalities. Over a 26-year period about 65,000 persons would die from truck accidents and 32,000 would die from train accidents.

CONCLUSION

All projected impacts for 26 years that are summarized in Table VII are small compared with radiological and nonradiological risk existing in daily life. An application of the same models and data used in this analysis would predict 117,000 latent cancer fatalities from natural background radiation in that same time period. Nonradiological truck and rail accidents would cause about 65,000 and 32,000 fatalities, respectively.

TABLE VI

Nonradiological Impacts (For 26 Year Period)

	Repository Location				
	GIR	Permian	Paradox	Yucca Mt.	Hanford
100% Truck					
Accident-Free--Latent Cancer Fatalities					
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
100% Rail					
Accident-Free--Latent Cancer Fatalities					
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	2.5
Accident--Injuries					
Occupational	10	13	17	21	22
Nonoccupational	1.8	2.3	3.0	3.6	3.8

TABLE VII

Total Risks for 26 Year Period

	Repository Location				
	GIR	Permian	Paradox	Yucca Mt.	Hanford
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

This preliminary work has been used to identify key parameters requiring refinement in future assessments. The sensitivity analysis performed in RADTRAN II has been used to provide a measure of the importance of each parameter to the overall accident-free analysis in terms of change in total dose. The amount of time spent at stops, the number of people at stops, and their distance from the cargo are currently receiving better definition. Future versions will also include reassessment of other important parameters such as numbers of waste shipments and packaging design.

ACKNOWLEDGMENTS

This analysis was produced through the coordinated activities of E. L. Wilmot and J. W. Cashwell of SNL, D. S. Joy of ORNL, and the author. P. E. Johnson and S. M. Gibson of ORNL, and P. C. Reardon of SAI performed the many computer calculations.

REFERENCES

1. E. L. Wilmot, M. M. Madsen, J. W. Cashwell, D. S. Joy, "A Preliminary Analysis of the Cost and Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites," SAND83-0867, Sandia National Laboratories, Albuquerque, NM (June 1983).

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

3. M. M. Madsen, E. L. Wilmot, J. M. Taylor, "RADTRAN II User Guide," SAND82-2681, Sandia National Laboratories, Albuquerque, NM (February 1983).

4. R. K. Rao, E. L. Wilmot, and R. E. Luna, "Nonradiological Impacts of Transporting Radioactive Material," SAND81-1703, Sandia National Laboratories, Albuquerque, NM (February 1982).

5. R. N. Smith and E. L. Wilmot, "Truck Accident and Fatality Rates Calculated From California Highway Accident Statistics for 1980 and 1982," SAND82-7006, Sandia National Laboratories, Albuquerque, NM (November 1982).

6. US Department of Transportation, "Accidents of Motor Carriers of Property," Federal Highway Administration, 1978 and 1979.

7. Association of American Railroads, "Yearbook of Railroad Facts," 1982.

8. US Department of Transportation, "Accident/-Incident Bulletin," Federal Railroad Administration, Years 1977 Through 1981.

9. D. S. Joy, P. E. Johnson, and S. M. Gibson, "HIGHWAY, A Transportation Routing Model: Program Description and User's Manual," ORNL/TM-8419 (December 1982).

10. D. S. Joy, P. E. Johnson, D. B. Clarke, and S. C. McGuire, "Predicting Transportation Routes for Radioactive Wastes," Waste Management 1981, Vol. 1, p 415.

11. "Spent Fuel Storage Requirements, An Update of DOE/8-0007," DOE/RL-82-1 (June 1982).