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THE COSTS AND IMPACTS OF TRANSPORTING NUCLEAR WASTE TO CANDIDATE REPOSITORY SITES

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INTRODUCTION

Public hearings held in states with potential candidate sites have pointed out the extensive public concerns regarding radioactive waste shipments. The Nuclear Waste Policy Act (NWPA) of 1982 (Section 112, "Recommendation of Candidate Sites for Site Characterization") specifically requires the Secretary of DOE to consider the cost and impact of transporting to the repository site the solidified high level radioactive waste and the spent fuel to be disposed of in the repository.

In this paper, a status report on the current estimated costs and impacts of transporting high-level nuclear wastes to candidate disposal sites is given. "Impacts" in this analysis are measured in terms of risk to public health and safety. Since it is difficult to project the status of the nuclear industry to the time of repository operation -- 20 to 50 years in the future -- particular emphasis in the paper is placed on the evaluation of uncertainties.

Transport is but one part of an overall disposal system. Indeed, other studies (Yates and Varadarajan, 1983)[1] have shown that optimizing the transport system does not necessarily result in an optimum overall disposal system. Similarly, transport costs and risks are not the sole consideration in any of the various siting decisions. It is just one important consideration that needs to be addressed.

The results presented in this analysis rely heavily on work performed by the staff of the Transportation Technology Center and on work by David Joy of the Oak Ridge National Laboratory. The results of these efforts have been reported by Wilmot, et al. (1983)[2].

The first part of this paper briefly describes the characteristics of the waste that must be transported to a high-level waste disposal site. This discussion is followed by a section describing the characteristics of the waste transport system. Subsequent sections describe the costs and risk assessments of waste transport. Finally, in a concluding section, the effect of the uncertainties in the definition of the waste disposal system on cost and risk levels is evaluated. This last section also provides some perspectives on the magnitude of the cost and risk levels relative to other comparable costs and risks generally encountered.

WASTE CHARACTERISTICS

The wastes slated for disposal in a deep geological disposal system arise from the spent fuel discharged from commercial nuclear power plants. The NWPA specifies that the size of the first repository will be limited to accommodate wastes arising from 70,000 metric tons of uranium in spent fuel until a second repository is operational. A 70,000 MTU repository capacity is used as a basis for this analysis.

One of the uncertainties in the analysis is the extent to which spent fuel will be processed prior to disposal. If spent fuel is reprocessed to remove essentially all the uranium and plutonium, all the residual wastes will be solidified and sent to the repository in one of four waste classifications. Most of the highly radioactive waste products are solidified and immobilized in a matrix such as glass. This waste is referred to as commercial high level waste (CHLW). The zirconium cladding and other structural material associated with a spent fuel assembly is another waste form referred to as "Hulls". These Hulls contain significant quantities of isotopes that emit highly penetrating radiation and, as a result, must be handled remotely and transported in shielded casks. The two other waste forms to be disposed of in a high level waste repository are called remote handled transuranic waste (RH-TRU) and contact handled transuranic waste (CH-TRU). Transuranic wastes contain significant quantities of elements with atomic numbers above uranium. The sources of these wastes are failed equipment, filters, and cleanup wastes. Like the Hulls, RH-TRU is shipped in heavily shielded casks. Many studies have been performed to estimate the number of packages of waste that must be handled if spent fuel is disposed of directly in a repository or if the spent fuel is first reprocessed. A reference set of waste quantity data is shown in Table 1. These values are used to develop the base case transport scenario in the next section. Also included in the table, under the category "Other Wastes", are high-level wastes arising from defense high-level waste processing. A total of 6,720 HLW glass logs from the processing of defense wastes at DOE's Savannah River Plant (DHLW) and 300 HLW glass logs from the processing of high-level waste at West

TABLE 1 BASE CASE WASTE QUANTITY DATA - 70,000 MTU REPOSITORY 50% SPENT FUEL AND 50% REPROCESSING WASTE

Waste Form	Number of Canisters Per MTU Processed	Canister Configuration	Number of Canisters in Base Case
Spent Fuel			
PWR(a)	-	-	54,400
BWR	-	-	70,000
Reprocessing Waste			
CHLW	0.438	13" dia. X 120" long	15,350
Hulls	0.150	30" dia. X 120" long	5,260
RH-TRU	0.750	30" dia. X 120" long	26,300
CH-TRU	5.26	55 gal. drums	184,200
Other Wastes			
DHLW	-	24" dia. X 118" long	6,720
WV-HLW	-	24" dia. X 118" long	300

(a) Based on current spent fuel projections (U. S. Department of Energy, 1983) , the PWR/BWR split is 0.635/.365 by weight for the first 70,000 MTU of spent fuel discharged from commercial nuclear power.

Valley, New York, (WV-HLW) are included in this category.

There are some major uncertainties in the values shown in Table 1. To estimate the impact of these uncertainties, two alternatives are evaluated -- one for spent fuel, the other for reprocessing waste. For spent fuel, some utilities have announced plans to disassemble the spent fuel and place the spent fuel rods in boxes to make more efficient use of their limited spent fuel storage capacity. If this is done, the number of packages that will need to be transported will be reduced by half. For the reprocessing waste case, recent studies performed by Allied General Nuclear Services (AGNS) have shown that it may be possible to reduce the volume of TRU waste by as much as 50% through additional treatment. The base case and these two sensitivity cases are analyzed in this paper.

WASTE TRANSPORTATION CHARACTERISTICS

In this analysis, transportation to five candidate sites, as shown in Fig. 1, is considered. These sites are named after the regions in which they are located -- the Gulf Interior Region (dome salt), the Permian Basin (bedded salt), the Paradox Basin (bedded salt), Yucca Mountain (tuff), and the Hanford reservation (basalt). It is assumed that wastes from 70,000 MTU of spent fuel will be transported to each of the sites.

For each site, the base case assumes that 35,000 MTU of spent fuel is declared to be waste and that 35,000 MTU of spent fuel is reprocessed and the resulting HLW and TRU wastes are sent to the repository. DHLW and WV-HLW are also included. For purposes of this analysis, the hypothetical reprocessing site is assumed to be Barnwell, South Carolina.

Sensitivity cases will consider 100% spent fuel assemblies, 100% disassembled spent fuel, 100% reprocessing waste, and 100% reprocessing waste with reduced TRU. Each of the sensitivity cases includes DHLW and WV-HLW.

The mode of transportation adds one additional variable to the assessment. Wastes can be shipped either by rail or by truck. The truck/rail split for the base case is shown in Fig. 2. For spent fuel, 75% is shipped by rail and 25% by truck. Wastes from reprocessing requiring heavy shielding are shipped by rail. Contact handled transuranics (CH-TRU) are shipped 50% by rail and 50% by truck. All DHLW from the Savannah River site are shipped by rail; West Valley wastes are shipped by truck. Sensitivity cases that consider 100% rail and 100% truck for all waste forms are also considered.

For the base case and for each of the sensitivity cases, the transportation system requirements, expressed in terms of number of packages, number of shipments and total shipment distance, are based on waste form data obtained from ORIGEN 2 (Croff, 1980)[4] calculations and on canister configurations being used in the NWTS Program current in 1982. Payload estimates for each of the transportation systems were based on shielding calculations using DOT allowable radiation levels and vehicle size and weight requirements for unrestricted shipment by both truck and rail. A summary of the shipment data to the repository for the base case is shown in Table 2. This table does not include the shipments to the reprocessing plant; if these are included, the number of shipments of spent fuel shown in Table 2 must be doubled. The result is an additional 10,300 truck shipments and 5,000 rail shipments.

The information in Table 2 can be used to construct all the sensitivity cases. For example, to

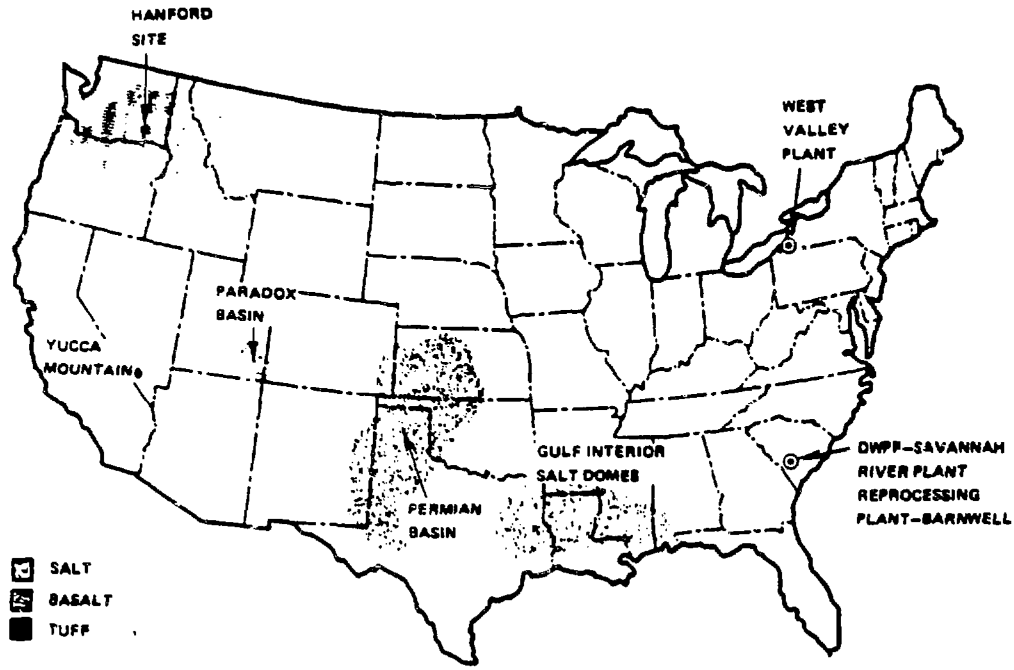

Fig. 1 Key Locations in Repository Transportation Assessment

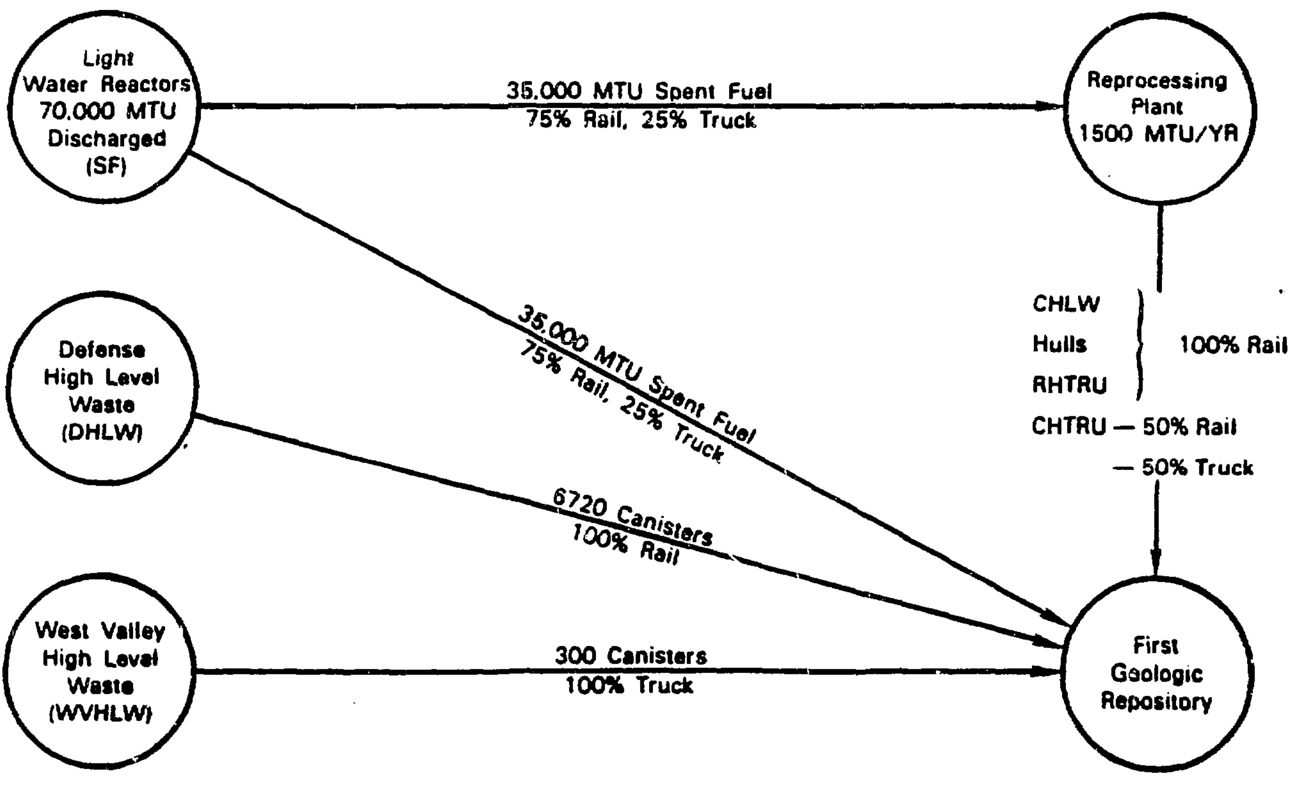

Fig. 2 Scenario for Repository Transportation Assessment

TABLE 2 BASE CASE SHIPMENT REQUIREMENTS TO REPOSITORY (50% SPENT FUEL, 50% REPROCESSED WASTE)

Waste Form	Number of Packages	Transport Index[(a)]	Truck[(c)]		Rail[(d)]	
			Payload[(b)]	Number of Shipments	Payload[(b)]	Number of Shipments
Spent Fuel						
PWR	54,400	20	2	6,800	12	3,400
BWR	70,000	20	5	3,500	32	1,640
Reprocessing Waste						
CHLW	15,350	20	1	0	12	1.280
Hulls	5,260	20	1	0	4	1,315
RH-TRU	26,300	4	1	0	4	6,275
CH-TRU	184,200	2	16	5,714	52[(e)]	1,771
Other Wastes						
DHLW	6,720	20	1	0	5	1,344
WV-HLW	300	20	1	300	7	0
Total				16,356		17,024

(a) Dose at one meter from package in mrem/hr
(b) Payload refers to number of fuel assemblies, canisters, or drums per transport package
(c) Loaded shipping weight for all waste types - 50,000 lb. maximum
(d) Loaded shipping weight for all waste types - 200,000 lb. maximum except CH-TRU is 140,000 lbs.
(e) 26 drums per package, 2 packages per rail car.

evaluate the number of shipments to a 70,000 MTU spent fuel repository using only truck transport, the number of packages of spent fuel shown in Table 2 must first be doubled since no reprocessing waste is to be included. Then the total number of shipments is obtained by dividing the number of packages by the truck payload for each of the categories being shipped to the repository, in this case the two spent fuel categories and the "other waste" category.

To obtain the shipment data for the disassembled rod case, consolidation studies have shown that the effective payload, measured in terms of spent fuel assemblies, is doubled. Thus half the spent fuel shipments are needed to ship the same quantity of waste. Table 3 shows a matrix of total shipments that might be received at a repository if various transportation and waste treatment options were to occur during the operational time period. The last line shows the result to the base case scenario described in Fig. 2.

TABLE 3 TOTAL LIFETIME SHIPMENTS RECEIVED AT A REPOSITORY

Waste Receipt Form	100% Truck	100% Rail
100% Spent Fuel Assemblies	86,224	14,588
100% Disassembled Spent Fuel	46,562	7,977
100% Reprocessing Waste	123,910	26,820
100% Reprocessing Waste (reduced TRU)	80,818	15,383
Base Case	33,380	

From the results given in Table 3, it is possible to specify a range of daily receipts that might be received if one of these particular conditions were to exist during the period of operation. These are summarized in Table 4. The largest shipment requirements pertain to the 100% reprocessing case. Converting these numbers to an average daily receipt rate results in values of 4 rail shipments and 15 truck shipments (see Table 4). Using the same procedure, 2 truck shipments and 2 rail shipments would be received in the base case on a typical day.

TABLE 4 TYPICAL RANGE OF DAILY RECEIPTS

	Daily Receipts[(a)]	
	Minimum	Maximum
Truck	0	15
Rail	0	4
Base Case	2 truck, 2 rail	

(a) 3,000 MTU/yr, 50 weeks/yr, 7 days/week

From the shipment data, two other characteristics of the transportation system fundamental to cost and risk assessments can be derived. They are the total shipment mileage and the fleet requirements. The following paragraphs will develop this information in a manner that exactly parallels the development of the shipment data summarized above.

To develop the mileage requirements, some additional information on the points of origin and destination for all the waste materials must be developed. The data have been reported by Wilmot, et al. (1983)[2]. In the analysis the reactor locations are coalesced into 21 centroids and a matrix of shipping distances from each centroid to the 5 potential repository sites shown in Fig. 1 is developed. Table 5 shows the estimated truck shipment miles for both the 100% truck and the base scenario case shown in Fig. 2. Table 6 develops similar data for rail transport.

The information in Tables 5 and 6 can be used to generate the effect of uncertainties in the characteristics of the waste and transport configuration on the overall shipment mileage. The range of shipment distances to each of the sites following analyses of each of the sensitivity cases is shown in Table 7. For both truck and rail minimum, maximum and base case values are shown. The minimum values for each mode refer to the minimum number of shipments required using only that mode of transport considering uncertainties. The absolute minimum is zero if the other mode were used entirely. The base case numbers are given at the bottom of the table for truck and rail. The minimum truck and rail shipment distances occurred when all the spent fuel was shipped as disassembled fuel rods. The maximum truck and rail shipment distances occurred for the 100% reprocessing waste cases. Comparing truck and rail, shipping distance is minimized by maximizing use of rail transport. Since risk is assumed to increase linearly, as shipment distance increases for any type and mode of shipment, the values in Table 7 are used in the risk calculation.

TABLE 5 ROUND TRIP TRUCK SHIPMENT DISTANCES[(a)] TO THE REPOSITORY SITES FOR 50% SPENT FUEL/50% REPROCESSING WASTE DISPOSAL

	Candidate Sites									
	100% Truck					Base Case				
Waste Form	GIR	Permian	Paradox	Yucca Mt	Hanford	GIR	Permian	Paradox	Yucca Mt	Hanford
Spent Fuel Assemblies	130	175	220	263	265	33	44	55	65	70
Reprocessing Waste										
CHLW	29	68	97	112	132	0	0	0	0	0
Hulls	9.5	24	34	39	46	0	0	0	0	0
RH-TRU	49	117	165	195	229	0	0	0	0	0
CH-TRU	22	49	73	83	97	11	25	39	42	49
Other Wastes										
DHLW	12	29	42	49	58	0	0	0	0	0
WV-HLW	1.1	1.5	1.9	2.3	2.4	1.1	1.5	1.9	2.3	2.4
Total	253	464	633	743	829	45	71	96	109	121

(a) Million Kilometers

TABLE 6 ROUND TRIP RAIL SHIPMENT DISTANCES[(a)] TO REPOSITORY SITES FOR 50% SPENT FUEL/50% REPROCESSING WASTE DISPOSAL

	Candidate Sites									
	100% Rail					Base Case				
Waste Form	GIR	Permian	Paradox	Yucca Mt	Hanford	GIR	Permian	Paradox	Yucca Mt	Hanford
Spent Fuel Assemblies	25	31	39	47	49	17	24	29	36	47
Reprocessing Waste										
CHLW	3.2	6.5	9.5	12	12	3.2	6.5	9.5	12	12
Hulls	3.3	7.0	9.5	12	13	3.3	7.0	9.5	12	13
RH-TRU	17	34	48	59	63	17	34	48	59	63
CH-TRU	4.5	9	13	33	34	4.5	9	13	17	17
Other Wastes										
DHLW	3.4	6.8	10	12	13	3.4	6.8	10	12	13
WV-HLW	0.2	0.2	0.2	0.3	0.3	0	0	0	0	0
Total	61	100	143	175	184	48	87	119	148	155

(a) Million Kilometers

TABLE 7 MINIMUM, MAXIMUM, AND BASE CASE ESTIMATES OF TRUCK AND RAIL SHIPMENT DISTANCES[(a)] TO CANDIDATE REPOSITORY SITES

	Candidate Sites				
Case Description	GIR	Permian	Paradox	Yucca Mt	Hanford
Rail Shipments					
Minimum	29	38	49	59	62
Maximum	69	130	198	244	257
Base Case	48	87	119	148	155
Truck Shipments					
Minimum	143	206	263	314	325
Maximum	233	548	782	909	1,068
Base Case	45	71	96	109	121
Base Case (Total)	93	158	215	257	276

(a) Million Kilometers

The last transportation parameter that is important in the cost calculation is the specification of the cask fleet requirements. To make these estimates, current experience was reduced to empirical formulas for average speed versus distance for truck and rail transport, cask turnaround time, and cask availability. Table 8 shows the minimum, maximum, and base case fleet requirements. As was the case with the shipment distance, the minimum occurs for shipping disassembled spent fuel by rail, the maximum occurs for shipping reprocessing waste by truck.

WASTE TRANSPORT COSTS

The transport costs for each of the receipt scenarios were calculated by adding fleet capital, fleet servicing and maintenance, and shipping charges. The range of costs are summarized in Table 9 for the various waste receipt scenarios described previously.

Fleet capital costs were based on transportation system characteristics and comparison with costs of existing transport systems. Servicing and maintenance costs were estimated by taking a fraction of the unit capital cost per year multiplied by the operation fleet size. It was also assumed in the capital cost estimates that the fleet would be completely replaced once during the repository operating lifetime for all waste types except for DHLW and WV-HLW. These two waste types are shipped to the repository during only a portion of the operating period. Freight charges were based upon published tariffs, where available, and estimates based on spent fuel shipments where no tariffs were published. Charges for physical security while in transit were based on current spent fuel escorting experience. These costs were applied to all waste forms. This is believed to be conservative in that current regulations do not include such requirements for reprocessing waste shipments. Additional charges for administrative functions and traffic management were not included. Such functions and related costs would be covered by the staffs at origin and destination facilities. Also, costs for construction of truck and rail access to repository receiving facilities were not included. These are assumed to be included in the repository cost. Neither has the cost of transport to the reprocessing site been included in the reprocessing waste transport cost estimate.

TABLE 8 MINIMUM, MAXIMUM, AND BASE CASE ESTIMATES OF RAIL AND TRUCK FLEET REQUIREMENTS[(a)]

	Candidate Sites				
Case Description	GIR	Permian	Paradox	Yucca Mt	Hanford
Rail Shipments					
Minimum	49	55	59	70	72
Maximum	145	189	223	250	250
Base Case	92	122	136	157	157
Truck Shipments					
Minimum	69	83	95	105	107
Maximum	117	249	249	319	319
Base Case	19	28	28	32	34
Base Case (Total)	111	150	164	189	191

(a) Number of casks

TABLE 9 MINIMUM, MAXIMUM, AND BASE CASE ESTIMATES OF TOTAL TRANSPORT COSTS[(a)] FOR SHIPMENT TO CANDIDATE SITES

Case Description	Candidate Sites: GIR	Permian	Paradox	Yucca Mt	Hanford
Rail Shipments					
Minimum	474	554	628	732	757
Maximum	1070	1530	1920	2210	2250
Truck Shipments					
Minimum	419	549	683	794	855
Maximum	734	1350	1760	2090	2350
Base Case (Total)	914	1231	1477	1704	1766

(a) Millions of $'s.

The results in Table 9 show the effect of uncertainty in the quantity and form of waste to be shipped to the repository. As was the case with shipment mileage, the minimum cost case for both truck and rail occurs when disassembled spent fuel rods are shipped to the repository. The maximum occurs in both cases when 100% reprocessing waste is received. The results show that the rail and truck cost differential is not a major factor. It should be recognized, however, that this situation could be considerably changed in a different economic environment, particularly if competition were not to occur.

WASTE TRANSPORT RISKS

Risk estimates have been made in terms of health effects -- injuries, deaths, latent cancer fatalities (LCF's) -- to both occurpational workers and the general public. Both normal operations and possible accident situations were considered. Calculations of non-radiological impacts were based on reports by, Rao, et al. (1982)[5] and Smith, et al. (1982)[6]. Radiological impacts were based on analyses described by Taylor and Daniel (1982)[7] and Madsen, et al. (1983)[8].

The non-radiological accident estimates were based on accident rate experience recorded in national transportation statistics. National accident predictions over the life cycle of repository operations are summarized in Table 10 for the various transportation receipt conditions being considered. These data included the effect of differences in accident rate as a function of population density as well as distance travelled. The effect of population density on accident rate can be seen by the lessened number of accidents to Hanford versus Yucca Mt., even though the mileage is about the same.

Of the total number of projected accidents, it is expected that less than two percent would be of such a severity that a radiological release is conceivable. Even though very unlikely, accidents of such severity and related conceivable releases have been included in the risk estimates.

The range of injuries and fatalities for the various repository receipt conditions are shown in Tables 11 and 12, respectively. The injury and fatality data were those which may result from ordinary traffic accidents for both truck and rail and were independent of the radioactive material present in loaded shipments.

The range of radiological impact measured in terms of LCF's is shown in Table 13. This estimate includes additional factors such as accident probability, severity, conceivable isotopic

TABLE 10 BASE CASE AND RANGE OF PROJECTED NUMBER OF ACCIDENTS THAT MIGHT OCCUR WHILE TRANSPORTING WASTE TO CANDIDATE SITES

Case Description	Candidate Sites: GIR	Permian	Paradox	Yucca Mt	Hanford
Rail Shipments					
Minimum	22	24	30	35	34
Maximum	52	82	121	144	141
Base Case	39	55	73	87	85
Truck Shipments					
Minimum	40	54	57	65	56
Maximum	66	143	171	189	184
Base Case	12	19	21	23	21
Base Case (Total)	51	74	94	110	106

releases, meteorological conditions, and population distribution. Because of the complexity of the problem and the number of scenarios and related waste types considered, the analysis was simplified by calculating unit risk factors that represent the impact for a unit distance of travel. These unit risk factors were calculated for each waste type and urban, suburban and rural population densities, and then combined with distances traveled to determine total impact. The results of the risk assessments summarized in Table 14 for the base case indicate that the only significant radiological risk is from normal transport, not from accidents. No immediate radiological injuries or deaths are expected from accidents.

The number of fatalities projected to occur from vehicle emissions was also estimated based on a technique reported by Rao, et al. (1982)[5]. These values are shown in Table 14 under the title pollution health effects. Since these values are so small, they were not included in any further analysis.

The ranges shown in Tables 11 to 13 were determined using the maximum shipment distances in Table 7. For the radiological case, the minimum case occurred when the repository received only spent fuel and all receipts were as disassembled spent fuel pins shipped by truck. The maximum radiological risk occurred when all spent fuel was reprocessed and the wastes were shipped by rail. In the case of the non-radiological injuries and fatalities, the minimum occurred when the repository received only spent fuel shipped via rail as disassembled spent fuel. The maximum case occurred when the repository received only reprocessing waste shipped via truck.

The basis for the risk values shown in Tables 11 to 14 was developed by Wilmot, et al. (1983)[2]. One of the unexpected results of the analysis was the finding that the radiological risk for rail transport was larger than for truck transport. This was not caused by the greater payload resulting in a higher accident risk for rail transport. The reason can be attributed to the lower average

TABLE 11 BASE CASE AND RANGE OF PROJECTED NUMBER OF INJURIES WHILE TRANSPORTING WASTE TO CANDIDATE SITES

	Candidate Sites				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Base Case	42	70	95	117	125
Range					
Minimum	6	7	9	11	11
Maximun	189	273	355	432	468

TABLE 12 BASE CASE AND RANGE OF NON-RADIOLOGICAL FATALITIES FROM TRANSPORT TO CANDIDATE SITES

	Candidate Sites				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Base Case	5	8	10	12	12
Range					
Minimum	0.6	0.8	1.0	1.2	1.2
Maximum	26	43	61	69	78

TABLE 13 BASE CASE AND RANGE OF RADIOLOGICAL LCF's[(a)] OR HEALTH EFFECTS FOR TRANSPORT TO CANDIDATE SITES

	Candidate Sites				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Base Case	13	19	22	26	27
Range					
Minimum	3.1	4.3	5.4	6.4	7.0
Maximum	17	25	31	36	37

(a) No immediate radiological health effects, only LCF's or genetic effects.

TABLE 14 BASE CASE TRANSPORT RISK SUMMARY

	Candidate Sites				
	GIR	Permian	Paradox	Yucca Mt	Hanford
Non-Radiological					
Injuries[a]	42	70	95	117	125
Deaths[a]	5	8	10	12	12
Pollution Health Effects	0.2	0.2	0.3	0.3	0.3
Radiological - LCF's[b]					
Normal Operations	13	19	22	26	27
Accidents	0.01	0.02	0.02	0.02	0.02

(a) Based on current accident statistics
(b) Estimates include present and future generations

speed of trains than for trucks. In the risk model, trains were estimated to stop 8.6 h/100 km versus 1.1 h/100 km for trucks. These 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 based on the assumption that rail shipments average 9.7 km/hr when stop time is included. When they are moving, they travel 24 km/hr, 40 km/hr and 64 km/hr in urban, suburban and rural areas respectively. Based on RADTRAN II results, the risk encountered by the general public while the train is stopped dominates the total risk and is the major reason why the rail radiological risk is higher than the truck risk. The values for stop time and the population exposure while stopped are very uncertain parameters. Additional studies have been initiated to refine the stop model and the input parameters to the model. It is believed that the current values are conservative and that the radiological risk estimates will decrease as better models and data become available.

Tables 12 and 13 point out two main considerations; the base case, which is projected to be a reasonable repository waste mix and transport mode mix, has a radiological risk which is quite close to the maximum and the non-radiological risk for the base case is quite close to the minimum. Thus, when considering the effects of future changes, the base case radiological risk values would not be expected to increase significantly, but could decrease significantly in the future as a result of changes in the types of waste received and transport mode utilization. Secondly, the range in risk values for the various fuel cycle scenarios has a greater effect on the risk parameters than the choice of site. Of course, the valid point remains that if the main goal of the transport program were to minimize the risk of transport at all costs, then the more eastern sites could be optimized to a lower value than the more western sites.

The maximum exposure to an individual is yet another measure of the transport risk. Table 15 presents the range of estimates for the maximum individual dose results assuming the individual is 30 meters from all shipments and the transport vehicle (truck or rail) moves past the individual at 24 km/hr (15 mph). Over the 26 year operating period of the repository, the cumulative individual dose received ranges from 6 mrem to 72 mrem. On an annual basis, the maximum individual exposure values range from 0.3 to 3 mrem/yr. For the reference scenario shown in Fig. 2, the dose received by the maximum individual is 35 mrem over the 26 year operating period or approximately 1.4 mrem/yr. Assuming the average individual receives 100 mrem/yr. from natural background, the maximum exposed individual would receive an increase above background ranging from 0.3 to 3 percent as a result of waste transport. The expected value is about one percent of background during a typical year.

TABLE 15 RANGE OF ESTIMATES OF THE MAXIMUM INDIVIDUAL DOSES FOR A 26 YEAR PERIOD

Case Description	Dose (mrem)
Rail Shipments	
Minimum	6
Maximum	12
Truck Shipments	
Minimum	31
Maximum	72
Base Case (Total)	35

The previous paragraphs have presented many data regarding the costs and risks of nuclear material transport to candidate repository sites. It is important to place these values into perspective to be meaningful. All the results have been based on 26 years of repository operation. In the same time period, and using the same models and data as used in this analysis, 117,000 LCF's would be predicted in the nation from background radiation. Based on the accident data for 1982 (National Safety Council, 1983)[9], a comparable number of individuals would be predicted to die during the 26 year period as a result of accidents involving truck tractors and semi-trailers. For transport of freight by rail, the comparable numbers of fatalities are 29,000 individuals. With respect to cost, nearly 1×10^{12} dollars would have been spent by consumers of the electricity produced from which these wastes resulted. Some additional comparisons are summarized in Table 16.

TABLE 16 TRANSPORT COSTS AND RISK PERSPECTIVES

- Waste transport costs range from 0.05% to 0.2% of the cost to consumers using electricity generated by nuclear power
- Waste transport vehicle miles traveled range from 0.002% to 0.07% of commercial freight mileage over a comparable period of time
- Fatalities predicted from waste transport accidents range from 0.001% to 0.05% of the current annual total for commercial freight
- LCF's range from 0.003% to 0.03% of those attributable to natural background
- Maximum individual exposures range from 0.2% to 3% of natural background radiation

COMPARISON WITH PREVIOUS WORK

The results shown here are based on recent Sandia work (Wilmot, et al., 1983)[2] but are quite different from results presented in previous assessments done within the NWTS program by Joy, et al. (1980)[11] and Baker, et al. (1977)[12]. In past assessments, the frequency of non-radiological fatalities per unit of travel for truck and rail were about equal. In a recent study reported by Sandia (Smith and Wilmot, 1982)[5] data was collected on accidents of trucks as a function of population zone -- rural, suburban, or urban. When these data are incorporated into the risk calculation and are then coupled with the assumption that the rail cargo payload is approximately five times greater than the truck payload, the number of fatalities for rail becomes about an order of magnitude lower than for truck results for transport of the same quantity of waste. Previous estimates showed only the effect of the difference in payload (i.e., reduced number of shipments) between truck and rail.

The radiological risk calculations also show some major differences. Previous estimates have considered exposure from accidents which are severe enough to release material as well as exposures to the population from passing casks. The estimates here are quite similar to previous estimates for these exposures. In the present calculation, a new model for exposure to the general population from stops during transit was considered. The stops model incorporated in RADTRAN-II was developed following observation of both truck and rail shipments. Incorporating the results of these observations into the model shows that the dominant exposure to the general population occurs at stops. The results show that the risk of release in a severe accident which has been the focus of many past transport studies, poses a lower risk than exposure from casks during stops. This last statement is not meant to imply that additional modeling of releases is not important. Rather, it points out that other components of the risk equation need to be studied with equal thoroughness.

Sensitivity analyses show clearly two parameters in the stops model where additional data would be useful. The duration of stops has a large effect on cost and risk. The number of people around the cask while stopped is important for risk analysis. In the risk model, trains were estimated to stop 8.6 hrs/100 km versus 1.1 hrs/100 km for trucks. Reducing the train stops to 4.3 hrs/100 km reduces the LCF's by 50 percent for the train cases. Reducing the number of people exposed while stopped by a factor of two also reduces the LCF's by 50 percent. Additional studies of the rail stops model have been initiated by Sandia.

For perspective, the current modeling of the stops can be compared with the exposure received by the population around the reactors that generated the waste being transported. Based on an assessment of population doses from operating plants in 1975 (Baker et al., 1977)[12], the population dose was 1,300 person-rem for the generation of 170 X 10^{12} watt-hrs of electricity or 7.6 person rem/10^{12} watt-hrs of electricity generated. A repository with a capacity of 70,000 MTU contains waste from fuel that has generated an estimated 500 X 10^{12} watt-hr/yr of electricity. The associated population exposure from reactor operation would be 4,000 person-rem/yr or 0.8 LCFs/yr. Multiplying by the 26 year operating period results in 20 LCFs which falls in the range of values for the LCFs estimated for nuclear waste transportation. Thus the transport LCFs shown are very comparable to the LCF of operating plants generating the waste. An additional perspective - if the same person-rem/LCF conversion factor were used for background radiation, 117,000 LCFs would be projected to occur during the 26 year operating period from background alone.

The comparison among the five candidate sites shown here considered only the first repository. Siting of the second and subsequent repositories can have a significant effect on both costs and risks. Previous assessments (Kirby, et al., 1979)[13] of the regional concept indicated that transportation cost and risk may decrease by as much as a factor of two by optimal regional siting of 2 or 3 repositories.. Such differences are comparable to the differences in costs and risks between repository sites reported here. Accordingly, additional transportation analyses of the regional siting concept are needed. Such studies are expected to show that the penalty for remote siting of one of the repositories is lessened.

CONCLUSIONS

The results shown here represent an attempt to estimate the range of costs and risks of transporting waste materials to five potential repository sites. Considering uncertainties in waste volumes, processing and transport mode, the sensitivity analyses show that the costs, while significant, are a small percentage of the revenues received from electrical power generation facilities that generated these wastes. Risks, even after considering uncertainties in the modeling, the waste form, transport mode, and repository location, are a small fraction of the risks imposed on the general public by both transportation of commercial freight and by natural background radiation. Thus the costs and risks could be judged to be acceptable.

As a result of these calculations, areas were identified where there were significant modeling uncertainties. Important transport characteristics were also identified. Additional modeling in these areas is expected to reduce uncertainties and quite likely will further reduce the radiological impacts shown in this paper. Risk minimization of the transport system, so long as it is not at the expense of other components of the overall disposal system, is a worthwhile goal and is made possible by carrying out calculations such as those shown in this paper.

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