RADIATION DOSES FOR A TRANSPORTATION SYSTEM AND ITS INTERFACE OPERATIONS FOR COMMERCIAL SPENT FUEL

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ABSTRACT

This paper gives the results of estimates of aggregated radiation doses to the affected public and workers associated with loading spent fuel at the reactors, transporting the spent fuel by truck and rail, and receiving and unloading the spent fuel at a deep geological repository. The estimates are for a postulated transportation-related system using current state-of-the-art technology, if employed in the high-level waste management system in the future, and the approximate dose reduction from some potential system improvements. The results of the study provide a starting point for the U.S. Department of Energy (DOE) to develop an improved transportation system that is cost effective, safe, and results in low radiation doses.

INTRODUCTION

DOE is responsible for implementation of a waste management system for a) receipt of spent fuel from commercial nuclear power reactors, b) transporting the spent fuel to a federal repository where c) the spent fuel is received and unloaded into a receiving facility, d) preparing it for disposal, and e) emplacing the spent fuel in a deep geologic repository. The U.S. DOE is committed to carrying out these activities in a safe and cost-effective manner. Therefore, the transportation system and its interfaces (loading of spent fuel at the reactor, and unloading at the repository) should be designed to keep radiation doses to the public and occupational workers acceptably low while keeping the system cost effective.

The principle of ALARA is being used to determine and implement cost-effective changes in the system that could reduce those doses. Because of this interest in including ALARA considerations in implementation of safe and cost-effective federal waste transportation system, DOE's Office of Civilian Radioactive Waste Management (DOE/OCRWM) initiated a study at PNL to assess cost versus radiation dose reduction tradeoffs associated with potential alternatives for transportation system design and operations.

In this study, a system has been postulated as a reference for transporting spent fuel from commercial nuclear power reactors to a DOE repository for packaging and disposal, based largely on the requirements in the OCRWM System Requirements and Descriptions document (1). This postulated reference system is defined for use in this study only. No officially designated reference reactor, transportation system, or repository exists or has been defined at the current time. Estimates of the worker and public radiation doses that would result from routine operation of this postulated reference system have been developed and are summarized here along with preliminary estimates of dose reduction from potential system changes.

The overall results of the first phase in this study (evaluating doses for a postulated reference system) have provided a baseline for comparisons in the second phase. The results from the ongoing second phase (evaluating cost effectiveness of potential alternatives for reducing doses) along with other program input, will provide technical information for use by DOE in their development and procurement of transportation casks, in their design and operation of transportation casks and their respective interface systems, and in their development of operating policies and procedures for the spent fuel transportation system.

The operational activities evaluated in this study include those in the following three major functional steps in the system: a) receiving empty transportation casks at a typical commercial nuclear power reactor and in-pool loading of the casks with spent fuel, b) transporting the spent fuel (dry) in the casks across the continental U.S. to a repository, and c) receiving the loaded transportation casks at a repository, dry unloading of the spent fuel and placing it into lag storage, and preparing and discharging the empty casks for their return trips. Spent fuel cask loading and shipping operations at the reactor are part of the spent fuel management system. Although these operations are not part of the federal system, they are included in the study system because design features and operations in the federal part of the system can impact them.

POSTULATED REFERENCE TRANSPORTATION SYSTEM

The postulated reference transportation system in this study is a "snapshot" of a system representative of current technology, its applications and operating practices (using "hands-on" techniques). It contains all the functions needed in any transportation system. A listing of the major features of the postulated reference system is summarized in Table I. Past and current transportation of spent fuel in the U.S. has generally involved spent fuel that is markedly less radioactive than the design basis for the shipping casks used, thereby resulting in external dose rates from the cask that are several-fold below these regulatory limits. Thus, in the postulated reference study system, estimated doses to the workers and the public are somewhat higher than past experience might indicate. The new generation of shipping casks and their handling systems will be designed to *maximize* payload within regulatory limits and using the principle of ALARA, and will certainly result in lower radiation doses than in the postulated reference cask system. A key basis in the postulated reference system is shielding that is provided on the loaded shipping casks to exactly meet Department of Transportation (DOT) regulatory limits on external dose rates.

Shipment Information

The overall shipment information for the postulated reference transportation system, based on this study's system definitions and analysis results, is summarized in Table II. The number of truck

TABLE I

Summary Description of Postulated Reference Transportation System

Reactor-Contemporary large PWR, pool storage and in-pool cask loading

Repository-Spent fuel dry receiving and handling facility similar to the advanced conceptual design of the MRS facility (2) using "hands-on operations.

Transport Casks-Legal-weight (25 tons) truck and 100-ton rail, including spent fuel;

- Description similar to DOE fact sheets (3); handling similar to existing casks;
- Capacity 14/36 PWR/BWR assemblies by rail; 2/5 PWR/BWR assemblies by truck;
- Shielding to meet DOT regulations.

In-Transit Conditions

- 3,000 MTU/yr shipped
- 70 wt% rail/30 wt% truck transport of spent fuel
- Rail/truck route distances 3070/2860 kilometers (1910/1780 mi)
- Rail by general freight; truck by general commerce

Spent Fuel Radiation Source

- Standard PWR, 10 years old, 35,000 MWD/MT
- 0.462 MTU/PWR assemblies, 0.186 MTU/BWR assembly

TABLE II

Overall Shipment Information

Parameter	Rail	Truck	Total
Average Shipments/Yr	320	971	1291
Average Casks/Day Received at Repository[(a)]	0.9	2.7	3.6
Average Reactor Turn-around Days			
PWR	1.0	0.6	--
BWR[(b)]	1.2	0.7	--
Average In-Transit Days			
To Repository	10.8	3.1	--
From Repository	10.8	2.0	--
Average Repository Turn-around Days			
PWR	0.9	0.6	--
BWR	1.2	0.7	--
Average Total Round-Trip Days/Shipment			
PWR	23.5	6.3	--
BWR	24.0	6.5	--

(a) Repository receiving 365 days/yr, 24 hr/day (DOE 1985a).

(b) Reactor fuel loading and shipping operations 24 hr/day.

shipments would be three times the number of rail shipments, but truck shipments require significantly shorter in-transit time than rail shipments because of the higher average speed and few and shorter stops for trucks. The estimated turnaround times for the casks include allowance for normal operational delays but not for times in queues while awaiting handling in the receiving and handling building at the repository.

Estimated Radiation Doses in the Total System

Shielding analyses were performed to provide information for developing the conceptual configuration of the postulated reference truck and rail casks (e.g., cavity size, weight, shield thickness and materials). These analyses confirmed that the DOT external dose-rate criteria were just met, and that the payload capacity requirements and gross vehicle weight restrictions were satisfied. Radiation dose-rate maps were then developed for the areas around the casks. The dose rate map for the postulated reference rail cask is shown in Fig. 1.

Operations within the postulated reference system were evaluated using time/motion studies to estimate times, locations, and exposure rates for the affected members of the public and workers for each activity within the system (taking into account the radiation from the casks and from other manmade radiation background in the work areas). These analyses were based largely on review of available information, with consensus judgment of the authors used where information was unavailable or conflicting.

The time/motion analyses were combined with the dose-rate field information around the casks and general-area background radiation dose rates from other facility sources to estimate radiation doses to the affected public and to workers, i.e., occupational radiation workers at the reactor and at the repository receiving and handling facility, and to transport workers while shipments are in transit.

In this analysis, the affected members of the public are those that are near enough to a loaded transport cask that they can receive a measurable radiation dose. These public members do not include any of the reactor or repository workers or the transport workers. The radiation workers at the reactor and the repository are those workers at those facilities that participate in the handling and loading or unloading of the transportation casks/vehicles. In this analysis, the transport worker category includes all who play an occupational role in completing the shipments, such as truck drivers, service station attendants, state highway and railroad inspectors, train crews, railroad train handling and service crafts, and escorts.

A summary of the estimated overall unit radiation doses for the postulated reference transportation system is given in Table III. (These should be compared with preliminary values given for alternatives in Table IV). The authors believe that for the bases used, the dose results should be within about ±25% of expected average or typical values in most cases but may be somewhat less accurate in some cases. The table shows that the aggregated doses (person-mrem/MTU) to the workers are higher than to the public for either shipment mode. It should be noted that the doses to the public are spread over millions of public members, (who would receive an average of less than 1 percent of natural background doses) while doses to the workers are spread over a few hundred. Thus, individual doses to the average affected members of the public are at least one-thousand-fold lower than

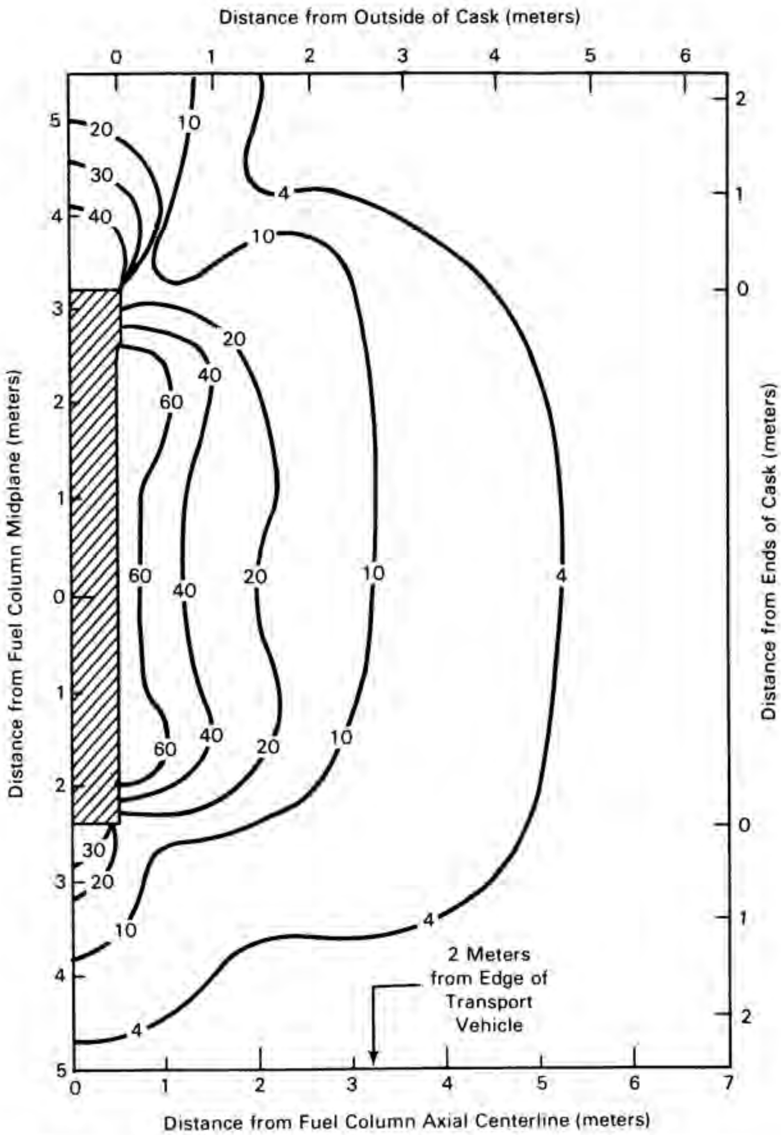

Fig. 1. Iso-Dose Contours for Postulated Reference Truck Cask.

TABLE III

Summary of Unit Radiation Doses from Postulated-Reference Transportation System Activities

Doses, person-mrem/MTU by Shipment Mode(a,b,c)				
Location of Activity	To Public Rail	To Public Truck	To Worker Rail	To Worker Truck
Reactor	(d)	(d)	60	290
In-Transit	6	500	5	90
Repository	(d)	(d)	70	300
Total	6	500	135	680

(a) See Table V for effects of system changes on these doses.

(b) Values are for either 100% rail or 100% truck transport; for pro-rated doses, multiply rail values by 0.7 (shipment fraction) and truck values by 0.3, then sum the results.

(c) Shown for PWR fuel only; doses for BWR fuel are comparable.

(d) Previously shown to be insignificant, and not evaluated in this study.

those to the average worker. There is essentially no dose to the public from transportation activities at the reactor or repository (2); all the dose to the public is received during the in-transit activities (i.e., outside the fences of the reactors and the repository in the "public domain" where uninvolved members of the public may be near enough to the casks to receive exposures). Public doses per unit of spent fuel shipped by truck are about 80-fold higher than for rail shipments, primarily because of the fewer but larger shipments made by rail and the few public members near enough to the rail shipments to be affected by them.

Worker radiation doses occur during each of the three major steps in the transportation activities (i.e., during at-reactor, in-transit, and at-repository operations). Nearly 5-fold higher aggregated worker doses are associated with the smaller-capacity casks shipped by truck than with the larger casks shipped by rail. Aggregated in-transit worker doses per unit of spent fuel shipped are lower than at the reactor or repository, and are about 20-fold higher by truck than by rail. Truck shipment doses are higher because of the proximity of the truck transport workers for significant time periods compared to the rail transport system. Aggregated worker doses for either rail or truck shipments are estimated to be about the same at the reactors and at the repository per unit of spent fuel shipped.

Estimated Aggregated Radiation Doses Associated With Specific Transportation Activities

The activities within the three steps in the reference transportation system that produce the highest aggregated unit radiation doses, i.e., person-mrem/MTU, are given in Table IV, along with the estimated doses from those activities. These findings were used as major bases for identifying system changes that could reduce doses.

TABLE IV

Estimated Percent of Aggregated Radiation Doses from Major Activities in Principle Portions of the Postulated Transportation System[a]

Activity	Percent of Worker Dose		Percent of Public Dose	
	Rail	Truck	Rail	Truck
AT-REACTOR				
Working on cask lids	40	40	--	--
Installing IL, TD, PB[b]	15	20	--	--
Loading spent fuel[a]	15	5	--	--
All of 21 other activities	30	35	--	--
Totals	100	100		
IN-TRANSIT				
Moving enroute	5	60	45	10
Activities at stops	95	40	55	90
All others	0	0	0	0
Totals	100	100	100	100
AT-REPOSITORY				
Working on cask lids	75	70	--	--
Removing IL, TD[b]	15	20	--	--
Wash, monitor, inspect cask	3	6	--	--
All of 21 other activities	7	4	--	--
Totals	100	100	--	--

(a) Values given for PWR fuel only; values for BWR fuel are comparable except doses for loading BWR fuel assemblies are somewhat higher.
(b) IL = impact limiters, TD = tie-downs, PB = personnel barriers.

Transportation activities at reactors start with receiving the empty transportation cask at the site fence and end with moving the loaded cask to the site gate where it is connected to the transportation carrier's prime mover for shipment to the repository.

Transportation activities in transit include those associated with the normal movement of the load over highways or railroads, and those that occur while the vehicle is stopped. Activities at stops include refueling, inspections, driver resting/eating, train make-up and crew changes. Radiation doses are received by the transport workers, and by members of the public who may be bystanders at stops, who are traveling along or nearby the route, and who live or work within the radiation field of the cask.

Transportation activities at the repository start with receiving the loaded transportation cask at the site gate and end with moving the vehicle with its empty cask to the site gate where it is connected to the carrier's prime mover. In addition, wet decontamination of the cask internals is assumed to be done at the repository on each cask after every tenth trip. This activity has essentially no effect on the aggregated doses at the repository (because it is done remotely in a shielded hot cell), but it adds about 7 to 8 hours turnaround time for the casks.

As shown in Table IV, workers' aggregated radiation doses at the reactor and repository are dominated by activities where the workers are near the cask, particularly when they are working around the cask lid area. These activities result in at least 40% of the total aggregated worker doses at the reactor, and about 70% at the repository. Doses to the workers at the reactor and the repository from the next largest dose-producing activity (working on the cask tie-downs, impact limiters, and personnel barriers) account for 15 to 20% of the total aggregated doses at those facilities.

Doses to reactor workers resulting from in-pool loading of spent fuel into the cask account for 5 to 15% of their total aggregated doses. Doses to the workers resulting from all of the remaining 21 activities account for about 30% of the total aggregated worker doses at the reactor, and 4 to 7% at the repository.

Radiation doses to the public result from activities where the people are near the casks while the shipments are in transit. In this case, the majority of public doses result primarily from the activities while the vehicles are stopped, especially in truck shipments.

Estimated annual radiation doses to maximally exposed individuals are being estimated for the postulated reference and alternative transportation system, but presentation of those results is premature and beyond the scope of this paper.

PRELIMINARY ANALYSIS OF ALTERNATIVES

The results from the postulated reference system analyses (Table III) show that the majority of the system radiation dose is associated with truck shipments, due to the large number of shipments required (shown in Table II) when using the reference capacity legal-weight truck cask. Also, a large fraction of the system dose received at the reactors and at the receiving facility is associated with work on and around the top closure. This is because of the high dose rates in that area that would result from exactly meeting the regulatory end shielding requirements of no greater than 2 mrem/hr at the nearest long-term occupied location (i.e., driver's location for the truck cask). Therefore, two approaches to dose reduction are immediately suggested: increase cask capacity at constant external dose rate, and reduce closure area dose rates by increasing shielding in that area without reducing cask capacity. Preliminary results from dose analysis of these alternatives follow. Analysis of the cost effectiveness of these (and other alternatives being evaluated) is not yet done, and is not included in this paper.

Increase Cask Capacity

The first choice for reducing doses is to increase the truck cask capacity by using the larger (4 PWR/10 BWR) capacity overweight truck cask, which doubles the quantity of fuel transported per shipment. This has the effect of reducing the dose to the public by about 42% and to the workers by about 33%. The next choice is to use a rail cask that utilizes depleted uranium as the principal shield material. Preliminary estimates indicate that the 100-ton rail cask capacity could be increased to 27/58 PWR/BWR assemblies. This has the effect of reducing the dose from rail shipments by nearly 50%, reducing the system dose to the public by about 1% and to the workers by about 18%. The total effect on the system of increasing both truck and rail cask capacities would be a dose reduction of about 43% to the public and about 51% to the workers. The distribution of these resultant doses in the system are shown in the second and third rows in Table V. These should be compared with doses from the postulated reference system (adjusted for 70% of the spent fuel transported by rail and 30% by truck as shown in the first row in Table V).

Increase End Shielding

For this analysis, it was assumed that sufficient depleted uranium is added to the top and bottom cask shielding to reduce the dose rates around the top closure area by a factor of 20. It is estimated that such additions could be made without reducing the cask capacities. This alternative, if applied alone, would have almost no effect on doses to the public, but would reduce the total system doses to the workers by about 54%. When applied in concert with the increased cask capacities discussed above, the total effect would be a dose reduction to the workers of about 25%. The distribution of these dose reductions across the system are shown in the last row of values in Table V. The overall dose reduction from applying all three alternatives is about 43% for the public and about 76% for the workers.

Other Alternatives

A number of other alternatives are being examined, including quick-removal tiedowns and impact limiters, integral impact limiters, single-fastener closures, use of long-handled tools, and an assortment of small-effect but good common practice ideas. The effect of implementing these alternatives has not yet been fully evaluated but preliminary results indicate that their effects, in concert with the capacity and shielding alternatives discussed above, would reduce the total system dose to workers by an additional 5 to 10%. Another alternative being evaluated is the application of robotics and remote handling to the receiving and handling operations at the receiving facility. Results are not yet available for this last alternative, but are expected to reduce the doses significantly at the receiving facility.

CONCLUSIONS

The conclusions related to the dose analysis results obtained for the postulated reference system and to the preliminary dose analyses of potential changes for reduction of public and worker radiation dose are summarized below.

- Reduction of worker doses at the reactor and repository should emphasize improvements in design and operations associated with cask lids. In addition, designs and operations associated with installing/removing cask tie-downs and impact limiters should also be considered for reducing worker doses.

TABLE V

Reduction of Total System Dose From Alternatives Application(a,b,c)

	Person-mrem/MTU							
	Rail	Truck	Total	% Reduction of Public Dose	Rail	Truck	Total	% Reduction of Worker Dose
Postulated Reference System	4	149	153	--	98	206	304	--
Alternative Applied								
Replace LWT with Overweight Truck Casks	4	85	89	42	98	106	204	33
plus								
Use Depleted U in Rail Casks	2	85	87	43	44	106	150	51
plus								
Improve End Shielding in Truck and Rail Casks	2	85	87	43	23	49	72	76

(a) Doses are adjusted to reflect 70% of spent fuel shipped by rail and 30% by truck.
(b) Values are for PWR fuel only; values for BWR fuel are comparable.
(c) Values are shown as calculated to preserve the derivation of the numbers; however, the number of significant figures shown is not intended to imply accuracy to that level.

- Cask designs that increase cask capacity with no change in cask external dose rates will result in large reductions in radiation dose to both the public and workers.
- Adding shielding to cask ends without reducing cask capacity will result in significant reductions in radiation dose to the receiving facility workers.
- Improvements in casks and their handling system beyond those evaluated to date offer promise of additional significant dose reductions.

The aggregated doses estimated in this study of the postulated reference transportation system are being used as the primary basis for defining and evaluating alternative designs and operations, and for comparing the cost-effectiveness of alternative concepts for dose reduction in the system. The analysis of alternatives is underway and preliminary results of dose reduction from some alternatives are presented here. Results from detailed dose analysis of the postulated reference system and dose and cost analyses of the alternatives, along with input from other DOE studies, will provide input to DOE in their planning and designs for an improved transportation system and its interfacing components.

REFERENCES

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