Analyses of the Transportation of Spent Research Reactor Fuel in the United States*

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INTRODUCTION

The Transportation Technology Center at Sandia National Laboratories has analyzed the impacts of transportation of research reactor spent fuel from U.S. and foreign reactors for the U.S. Department of Energy's (DOE) Office of Defense Programs. This effort represents the first comprehensive analytical evaluation of the risks of transporting high-, medium-, and low-enriched uranium spent research reactor fuel by both sea and land.

Two separate shipment programs have been analyzed (USDOE, 1986; USDOE, 1988): the shipment of research reactor spent fuel from Taiwan to the U.S. (Fuel Movement Program), and the return of research reactor spent fuels of U.S. origin from foreign and domestic reactors (Research Reactor Fuel Return Program). In order to perform these analyses, a comprehensive methodology for analyzing the probabilities and consequences of transportation in coastal waters and port facilities, handling at the port, and shipment by truck to reprocessing facilities was developed.

The Taiwanese fuel consists of low-burnup aluminum-clad metallic uranium research reactor spent fuel; the other fuels are primarily aluminum-clad oxide fuels. The Fuel Movement Program is ongoing, while the Fuel Return Program addresses future shipments over a ten-year period. The operational aspects of the Taiwanese shipments have been uniform, but several possible shipping configurations are possible for the Fuel Return Program shipments.

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The risks of transporting spent nuclear fuel and other radioactive materials by all modes have been analyzed extensively. Comprehensive assessments, which bound the impacts of spent fuel transport, demonstrate that when shipments are made in compliance with applicable regulations, the risks for all such transport are low (USNRC, 1977; USNRC, 1980; USDOE, 1980). For comparison with previously licensed transport activities and to provide continuity with earlier analyses, the results for shipment of 150-day-old commercial pressurized water reactor (PWR) spent fuel are presented as part of this study.

METHODOLOGY

The RADTRAN risk analysis code developed by Sandia National Laboratories (Madsen et al., 1986) was used to perform these analyses. RADTRAN calculates risks associated with the transport of radioactive materials. The RADTRAN code consists of two major modules: the incident-free transport module, in which doses resulting from normal transport are modeled, and the accident module, in which consequences and probabilities of accidents are evaluated and used to generate an accident risk estimate.

To address the risks of maritime transport in U.S. ports, potentially significant characteristics of U.S. port facilities must be considered. These characteristics include length of port approach channels, turnaround times, populations around ports, and depth of water within port facilities. Port approach channels, for example, determine the distance traveled by a ship in port waters (i.e. the length of a port transit). The use of bounding values for these parameters in the environmental documentation ensures that potentially suitable ports are not eliminated on the basis of these analyses.

The final destinations of all shipments considered in this analysis are the Savannah River Site (SRS) in Barnwell, South Carolina, and the Idaho National Engineering Laboratory (INEL) outside of Idaho Falls, Idaho. The actual fractions of foreign fuel arriving at Atlantic and Pacific ports, respectively, and the fractions going to each potential destination, are determined by the processing and storage capabilities at SRS and INEL. Since neither of these sites is immediately adjacent to a major U.S. port, representative overland routes to these destinations were determined from representative ports of entry on the Atlantic and Pacific Coasts (Portsmouth, VA, and Portland, OR). These port locations were used strictly for the purposes of analyzing relative risks of overland transport, and no parameters specific to these ports (e.g. population densities) were used for the analysis of maritime components of risk. Parameters regarding port characteristics were assigned values to maximize the risks to insure conservative estimates. Overland routes from ports (or port of entry) to receiving facilities were determined with the INTERSTAT routing model.

Incident-Free Risk

The magnitude of the incident-free risk depends in large part on the package dose rate or Transport Index (TI), the surrounding population density, and the number of handlers and crew members. The TI is defined as the dose rate in millirem per hour at one meter from the package surface. For these analyses, the TI was set at 1.4 for research reactor spent fuel, a conservative upper bound (Pearson, 1986).

The incident-free module for marine transport includes models describing:

- dose to persons between 200 and 1000 meters from the sea lane (measured from the center line of the sea lane);
- dose to persons sharing the transport link (sea lane);
- dose to persons at stops (docks);
- dose to ship crew
- dose to handlers (unloading)
- dose to warehouse personnel (storage)

Because the distance between ships in port-approach shipping lanes typically exceeds 1000 meters, no separate on-link dose was calculated. Dose to warehouse personnel was only calculated for the maximum annual risk case, in which a 24-hour storage period at a warehouse in the dock area was assumed for the Fuel Return Program.

Accident Risk

Accident risk is defined as the consequence of an accident multiplied by the probability of occurrence of that accident. In practice, any number of different accident sequences exist, each of which has an associated probability. Accidents may be grouped according to their severities. In RADTRAN, each such grouping is considered an Accident Severity Category, and a probability is assigned to each category. These probabilities are derived from historical data. The consequences are determined by assigning release fractions to each category for each physiochemically distinct group of radioisotopes. The release fraction is that fraction of the total package inventory that could be released in a given severity of accident. For relatively nondispersible forms such as spent fuel, many radioisotopes are difficult to release in particulate form even in a severe accident. The user assigns values by radioisotope group in each severity category for aerosolized and respirable aerosol fractions of any released radioactive material.

RADTRAN III contains a meteorological model that allows the user to define the behavior of a plume of particulates, if one is produced in the accident considered. Although the number of casks per shipment may vary, this does not affect the accident risk calculation because the data regarding accident scenarios in ports indicate that credible severe accidents would involve only a single cask.

The risk of transport of all types of spent fuel tends to be dominated by a few isotopes, including cesium-134 and cesium-137. The cesium isotopes are present in less volatile form in PWR and oxide-form research reactor spent fuels than in the metallic spent fuel shipped from Taiwan. This difference in chemical form compensates somewhat for the fact that metallic spent fuel contains much less cesium-134 and cesium-137 than does PWR or other oxide-form spent fuels. The dominant component of the risk associated with transport of PWR spent fuel is the cobalt-60 contribution from crud. Aluminum-clad spent fuel has little or no crud, and most of the research reactor spent fuel in this study is aluminum clad.

Total Risks

To calculate transport risks in ports, the unit risk per port transit is calculated for each fuel category and risk type and then multiplied by the number of port calls per shipment in U.S. waters. These products are summed to give total risk. For overland (truck) transport, the unit risk per kilometer is calculated for each population-density zone and risk type for each fuel category and then multiplied by the number of kilometers of travel in that population-density zone for each potential overland route. Again, the products are summed to give total risk.

Maximum Annual Risk

To determine the maximum annual radiological impact of spent research reactor fuel transport, several bounding conditions were defined. In each case, shipment rate was maximized, as were all factors affecting the total risk that could be identified on the basis of operating experience and equipment capabilities.

SUMMARY OF THE ANALYSES

Background--As is generally the case for massive Type B packages, the incident-free component of risk is greater than the accident component for port areas. This is true because the probability of radiological exposure from an accident is quite low, but the probability that crew and handlers in particular will experience some exposure during normal transport is unity.

The Taiwanese Research Reactor Shipments--The transportation of research reactor spent fuel from Taiwan to the United States by ship has been performed in two phases. Phase I of the analysis consisted of the shipment of 474 elements of 2-year-old spent fuel (i.e. fuel that was 2 years out of the reactor), while Phase II consisted of the shipment of 1100 elements of 1-year-old fuel. Risk analyses were performed for each phase, which were used by the DOE as the basis for two Findings of No Significant Impact, dated December 1986 and July 1988, respectively. Phase I shipments began in December 1986, and Phase II shipments, still in progress, began in July 1988.

The U.S. DOE assumed title to the fuel at the reactor and acted as shipper of record. A commercial broker arranged carriage. A maximum of 12 spent fuel shipping casks have been available for shipment of the Taiwanese fuel, although the actual number of casks per shipment may be less.

In the Phase II analysis, a maximum annual risk was calculated by assuming that all casks are fully utilized for the entire year for this shipping campaign alone. In reality, this is a very conservative assumption since these casks are also used for transfers of other materials, and time is required annually for maintenance and cleanup.

<u>The Research Reactor Return Program</u>--The DOE, in Federal Register Notice 52-FR-49198 dated December 30, 1987 (Federal Register, 1987), announced its intention to renew for an additional 10 years "...its policy of receiving, and making financial settlement for, United States origin spent reactor fuels from research reactors not owned and operated by the Department." This analysis supports the renewal of that policy and addresses the potential radiological impacts of transporting within the United States non-DOE research reactor fuel from foreign and domestic sources. This analysis also incorporates a bounding analysis for the maximum annual shipment configuration.

Projected shipments were based on historical shipment patterns for research reactor spent fuel together with operational constraints at each of the receiving facilities. A total of 481 elements could be shipped under this program with 129 originating in North America and 352 from the rest of the world. The origins of these latter elements are not important to the analysis, since only the risks in ports and on highways in the U.S. are considered. Risks resulting from handling, storage and processing at each of the receiving facilities (SRS, INEL) are covered by the respective facility environmental analyses. Detailed technical appendices of the full document on which this paper is based (U.S. DOE, 1988) include discussions of the regulatory structure, descriptions of the various types of research reactor spent fuel, radionuclide inventories, and projections of spent fuel shipments by fuel type and origin.

Three base cases were examined for the program duration:

- all overseas shipments arrive at Portsmouth, VA, and are transported to the SRS; North American shipments are made by truck.
- all overseas shipments arrive at Portland, OR, and are transported to the INEL; North American shipments are made by truck.
- shipments are distributed between SRS and INEL, all overseas shipments are made through the nearest port; North American shipments are made by truck.

For these cases, conservative assumptions were made regarding fuel types shipped, quantities shipped per cask, and operational conditions such as number of intermediate stops, duration of stops, and port locations. These are explained in the description of the method in the environmental assessment and supporting documentation.

For the maximum annual risk calculation, it was assumed that twenty percent of the total amount of fuel is shipped in a single year. Destinations were distributed proportionally according to maximum annual receipt rates at each of the facilities; the number of intermediate stops was increased from 2 to 3; and 24 hours of storage at the receiving port was included.

Comparison of the Study Parameters

Major features of the two spent fuel types are described and contrasted in Table 1.

TABLE 1. STUDY PARAMETERS

Study Parameters	Taiwanese	Spent Fuel Return
Fuel Type(s)	Metallic	Mostly Oxide
Amount Shipped	474/1100 rods	481 assemblies
Owner/Shipper	DOE	Foreign/Commercial
Duration of the Shipments (yrs)	3-5	10
Destinations	SRS/INEL	SRS/INEL
Representative Ports of Entry	Portland, OR Portsmouth, VA	Portland, OR Portsmouth, VA Champlain, NY*
Intermediate Port Calls (#)	0	3
Port Call/ Unloading Duration (Hrs)	0/24	24/24
Time in Storage (Hrs)	0	24
Average Cask Payload (MTU)	0.3	0.03
Casks per Ship	up to 12	1
Stowage Aboard Ship	Below Deck	Above/Below Deck
Overland Transport Mode	Truck	Truck

Summary of the Analysis

As shown in Table 2, the radiological risks of transportation are dominated by the incident-free risks. The risks in ports of maritime transport of all research reactor fuel were lower than those for commercial PWR spent fuel. In all cases the risk is small, which is consistent with DOE/EIS-0015 (US DOE, 1980).

In no case were acute effects predicted to occur as a result of an accident; thus, all radiological impacts may be expressed in terms of delayed stochastic effects (i.e. latent cancer fatalities).

TABLE 2.
SUMMARY OF AVERAGE ANNUAL RADIOLOGICAL RISKS OF TRANSPORT FOR RESEARCH REACTOR SPENT FUEL

	Highway		Port	
Shipment Type	Dose (person-rem)	LCFs	Dose (person-rem)	LCFs
TAIWANESE SPENT FUEL (1 year old)*				
Incident-Free	9.1E-01	1.1E-05	1.4E+00	1.8E-04
Accident	5.5E-04	6.8E-08	1.1E-02	1.3E-07
RETURN PROGRAM				
BASE CASE--SRS/INEL THROUGH NEAREST RESPECTIVE PORT				
Incident-Free	1.2E+00	9.0E-06	9.9E-01	2.0E-04
Accident	5.6E-07	1.1E-10	5.1E-04	1.0E-07
SRS THROUGH PORTSMOUTH, VA				
Incident-Free	1.1E+00	2.2E-04	9.9E-01	2.0E-04
Accident	5.3E-07	1.1E-10	5.1E-04	1.0E-07
SRS THROUGH PORTLAND, OR				
Incident-Free	3.9E+00	7.8E-04	9.9E-01	2.0E-04
Accident	2.0E-05	4.0E-09	5.1E-04	1.0E-07
INEL THROUGH PORTSMOUTH, VA				
Incident-Free	4.2E+00	8.4E-04	9.9E-01	2.0E-04
Accident	2.1E-05	4.2E-09	5.1E-04	1.0E-07
INEL THROUGH PORTLAND, OR				
Incident-Free	2.0E+00	4.0E-04	9.9E-01	2.0E-04
Accident	6.7E-07	1.3E-10	5.1E-04	1.0E-07

* The values for the Taiwanese shipments are based on 1-year-old fuel, although over 400 of the elements shipped have been at least 2 years out of the reactor.

The total radiological risk is dominated by the Incident-Free risk of highway transport. The radiological Accident risks of port transport are larger than those of highway transport. The port risks are similar for all Fuel Return Program alternatives because of the bounding values used in the analyses.

To calculate the maximum annual risk of transport for the Fuel Return Program, twenty percent of the total shipments were assumed to be received in a single year rather than the ten percent average rate. Thus, 96 shipments were assumed to be made in a single year. To bound the operational risks, all shipments were assumed to be high-enriched uranium spent fuel from origins that would require transport by ship. Three intermediate stops were assumed, rather than the two stops per shipment than were assumed for the base case. In addition, a 24-hour period of storage in a warehouse near the dock was assumed.

TABLE 3
SUMMARY OF THE MAXIMUM ANNUAL RADIOLOGICAL RISKS OF TRANSPORT OF SPENT RESEARCH REACTOR FUEL

Shipment Type	Highway Person-rem	Port Person-rem	Highway LCF's	Port LCF's
TAIWANESE (1 year old)				
Incident-Free	*	2.2E+00	*	4.4E-04
Accident	*	1.5E-02	*	3.0E-06
RETURN PROGRAM--BASE CASE (SRS/INEL)				
Incident-Free	2.9E+00	1.5E+00	5.8E-04	3.0E-04
Accident	5.6E-06	1.9E-03	1.1E-09	3.8E-07

* Not Calculated

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