Intermodal Transfer of Spent Fuel*

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INTRODUCTION

As a result of the international standardization of containerized cargo handling in ports around the world, maritime shipment handling is particularly uniform. Thus, handler exposure parameters will be relatively constant for ship-truck and ship-rail transfers at ports throughout the world. Inspectors' doses are expected to vary because of jurisdictional considerations. The results of this study should be applicable to truck-to-rail transfers.

A study of the movement of spent fuel casks through ports, including the loading and unloading of containers from cargo vessels, afforded an opportunity to estimate the radiation doses to those individuals handling the spent fuels with doses to the public along subsequent transportation routes of the fuel. A number of states require redundant inspections and for escorts over long distances on highways; thus handlers, inspectors, escort personnel, and others who are not normally classified as radiation workers may sustain doses high enough to warrant concern about occupational safety. This paper addresses the question of radiation safety for these workers.

Data were obtained during observation of the offloading of reactor spent fuel (research reactor spent fuel, in this instance) which included estimates of exposure times and distances for handlers, inspectors and other workers during offloading and overnight storage. Exposure times and distance were also measured for other workers, including crane operators, scale operators, security personnel and truck drivers. RADTRAN calculational models and parameter values then facilitated estimation of the dose to workers during incident-free ship-to-truck transfer of spent fuel.

CASE STUDY

This paper considers a case study of the intermodal transfer of 12 casks (in containers) of research reactor spent fuel in the Port of Hampton Roads, Virginia. The ship under study had berthed during the night at the southern end of the terminal at Newport News, Virginia. No ships were berthed nearby, the adjacent pier was not in use, and there was little activity near the ship while it was being unloaded. The casks had been loaded under supervision of the International Atomic Energy Agency (IAEA) at their point of origin, and three separate radiological inspections of each cask were performed at the entry to the port (Hampton Roads) by the U.S. Coast Guard, the state of Virginia, and the shipping firm. Additional inspections for non-radiological purposes also are performed.

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The casks were subsequently transported by truck to the USDOE Savannah River site in South Carolina. Use of the port properties and facilities are regulated by a state agency, the Virginia Port Authority (VPA). Container cranes are load-tested at least every four years, and the VPA requires that all cables be inspected immediately before use with highway-route-controlled quantities within port facilities. The VPA Risk Manager has the authority to select an appropriate terminal and berth for a ship carrying radioactive and other hazardous cargo. VPA Police escort all movements of highway-route-controlled quantities within port facilities. Historically, the probability of a drop resulting from a container failure is lower for shipments of this type than for ordinary containerized cargo; for the latter, the drop probability is estimated to be 2.7×10^{6} per single operation (or "move").

A spent fuel cask that is to be shipped to the United States by vessel is secured in an approved intermodal container of the type defined as a specially modified closed transport unit. All approved intermodal containers must meet minimal structural requirements, and intermodal containers used with massive spent fuel casks have additional structural reinforcement. The application of standards established by the International Convention for Safe Containers (ICSC) and the International Standards Organization to all intermodal containers has led to worldwide standardization of cargo handling procedures at ports. All major commercial ports in the world have container cranes specifically constructed to move this type of approved container. The procedures and manpower requirements for securing and moving a container with a crane from a ship to a truck chassis and vice versa are comparable in all ports.

Handler and Inspector Dose

Two groups, each consisting of four handlers and a spotter, transferred the container from the ship to the truck trailer. One handler was positioned at each corner of the container and the spotter checked that the tiedowns were secure. These ten people were at an average distance of one meter from each cask, for about 2 minutes per cask. A radiological inspection was performed on each container by the U.S. Coast Guard and the state of Virginia. The shipper also performed a radiological inspection, and replaced Chinese-language placards with English-language placards (Neuhauser and Weiner 1992). In addition, the inland carrier performed a mechanical inspection of the tiedowns. The configuration and location of inspectors and handlers during and after offloading are shown in Figure 1. The distances from the source and exposure times for individuals close to the cask are given in Table 1.

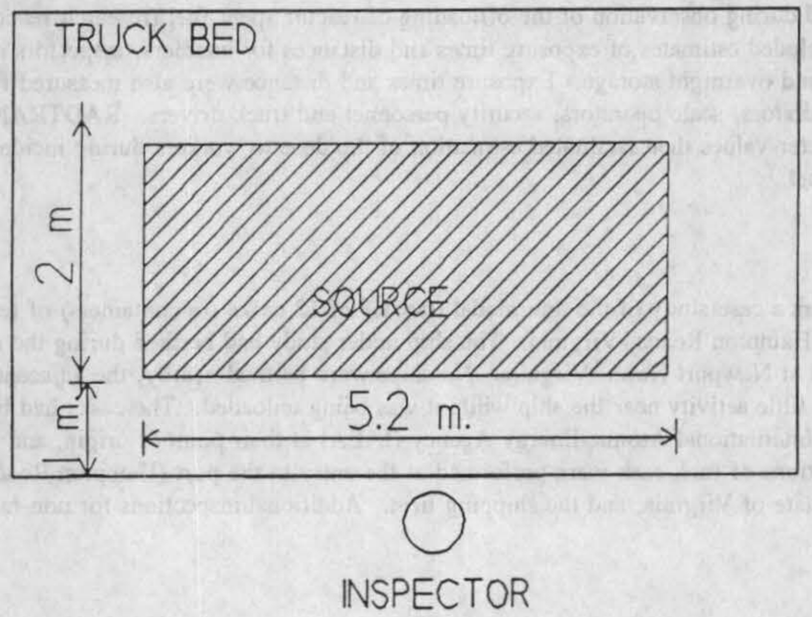

Figure 1. Configuration and location of inspectors and handlers during intermodal cask transfer.

The dose for incident-free handling was calculated using the RADTRAN 4 formulation of the dose to handlers of large packages (Neuhauser and Kanipe 1992)

$$D = \frac{K \cdot DR \cdot PPS}{r} \cdot T_H \cdot PPH \cdot N_H \cdot SPY \quad (1)$$

where D = population dose in person-mrem
K = line source coefficient = $(1+d_{eff}/2)$; d_{eff}, the effective package dimension = 4.68 m.
DR = dose rate in mrem/hr at 1 m. from the package surface
PPS = packages per shipment = 1
T_H = exposure time in hours
PPH = number of handlers
N_H = number of handlings per shipment = 2 for this calculation
SPY = number of shipments = 1 for this calculation
r = distance of handler from the source, in meters

Total dose for the 12 casks was calculated by multiplying the dose per cask by 12. This calculation overestimates the total exposure time, but was retained in the interest of conservatism. Table 1 shows the incident-free doses to handlers, spotters and inspectors for this particular case. For comparison, the allowed annual occupational whole body dose in restricted areas, as cited in 10 CFR 20.101(b)(2), is 50 mSv (5000 mrem), and the permissible occupational level of radiation in unrestricted areas, as cited in 10 CFR 20.105(a), is 5 mSv (500 mrem). The annual permissible level of general public exposure used by the U.S. Environmental Protection Agency (EPA), as cited in 40 CFR 191.12, is 0.25 mSv (25 mrem) per source.

Table 1. Doses to Handlers and Inspectors.

Personnel	PPH	r in meters	Exposure time; hours	Dose per container; 10^{-3} person-Sv (person-rem)	Total dose; 10^{-3} person-Sv (person-mrem)
Handlers	4	1	0.258	9.66 (966)	116 (11,600)
Spotters	1	2	0.258	1.21 (121)	14.5 (1,450)
Inspectors	5	1	0.083	3.90 (390)	46.8 (4,680)
Weighmaster	1	8	0.083	9.75×10^{-3} (0.975)	0.117 (11.7)

Dose to Escort Personnel

The U.S. Nuclear Regulatory Commission (NRC) requires an escort for a spent fuel shipment only in urban areas (10 CFR 73.37 and 49 CFR 173.22). The State of Virginia, however, requires an escort to the state border. Dose to escort personnel during incident-free transportation were calculated using the on-link incident-free dose calculation in RADTRAN 4. In this model the shipment is treated as a point source, since r is much larger than the package dimension, and that the dose is proportional to $1/r^2$ rather than $1/r$. The equation used is

$$D = \frac{N}{V} \cdot PPV \cdot \frac{DIST}{V} \cdot K \cdot \int_{min}^{\infty} \frac{1}{r^2} dr \quad (2)$$

where D = population dose in person-mrem
K = package shape factor for a point source
PPV = number of people per vehicle = 2
N = number of vehicles per hour
V = velocity in km/hr; $N/V = 1$ for this calculation
$DIST$ = segment length in km
r = distance of escort personnel from the source, in meters

Table 2 shows the dose to the escort personnel and compares it to the off-link dose (the dose to people along the route who are not moving with the shipment).

Table 2. Doses to Escort Personnel.

Route segment	Segment length; km	Escort dose; 10^{-9} person-mSv (10^{-9} person-mrem)	Off-link population	Off-link dose; 10^{-9} person-mSv (10^{-9} person-mrem)
NNMT to highway	3.3	2.64 (264)	2905	0.69 (69)
Norfolk	70	5.90 (590)	129049	11.8 (1180)
Norfolk/Portsmouth	45	3.80 (380)	71176	284 (28400)
Isle of Wight Co.	13	3.01 (301)	349	1.62 (162)
Suffolk	3.3	0.765 (76.5)	147	0.59 (58.9)
Emporia	3.3	0.765 (76.5)	345	13.8 (1380)
Greenville Co.[a]	117	27.6 (2760)	1431	6.43 (643)
TOTALS	255	44.5 (4448)	202497	318 (31820)

[a] The data for Southampton County are not given in the reference used, so data for Greenville County were used.

Table 4 compares the average individual doses of personnel involved with the shipment to the average urban, suburban and rural off-link doses. In making these calculations, a population of two individuals per escort vehicle was assumed, although in practice it may be as low as one person. In addition, the urban, suburban and rural averages were calculated according to the criteria shown in Table 3.

Table 3. Criteria for Identifying Urban, Suburban, Rural Segments.

	Population density range (per km^2)	Links used in averaging (from Table 2)
Urban	≥1285	NNMT to highway, Norfolk, Portsmouth
Suburban	55-1284	Suffolk and Emporia
Rural	0-54	Isle of Wight and Greenville Counties

CONCLUSIONS

Inspectors and handlers of shipments of radioactive materials are exposed to higher dose rates than any other transportation workers or members of the public. No cask or container is handled more than is necessary, and modern equipment and standardization have minimized handling time. However, the number of inspections is not restricted, each container is inspected several times even before leaving the dock, and the activities of inspectors are not so closely standardized as those of the handlers. Inspectors not only inspect for radiological contamination and for mechanical security, but change placards, fill out forms, watch other activities, and so on. Even the crew members participate in the inspections to the extent of tagging the tiedowns (a 15-minute operation, including walking around the container to tag each tiedown).

As may be seen in Table 4, the average radiation dose for an inspection of this particular shipment was almost 10% of the EPA limit to the general public of 25 mrem per source, about 0.5% of the permissible level of radiation in unrestricted areas, and about 240 times the average dose to the general urban population along the route (urban off-link dose) on this particular route. The average dose to escort personnel, on the other hand, is comparable to the off-link dose.

Table 4. Comparison of Average Individual Doses.

Receptor	Average individual dose; mSv (mrem)
Handler	0.0290 (2.90)
Spotter	0.0145 (1.45)
Inspector	0.00936 (0.936)
Weighmaster	0.00117 (0.117)
Escort	2.23×10^{-5} (0.00223)
Urban Off-link	9.88×10^{-5} (0.00988)
Suburban Off-link	0.720×10^{-5} (0.00072)
Rural Off-link	0.403×10^{-5} (0.000403)

Doses to Inspectors

Hoskins, et al. (Hoskins, et al., 1992) evaluated near-field personnel dose using a dose rate map. The dose rate at one meter from the surface of the cask studied by Hoskins was about ten times the dose rate at one meter from the surface of the Newport News container (1.29 mrem/hr as compared to 0.14 mrem/hr). Figure 2 compares Hoskins' measured dose rates perpendicular to the center of the cask to those calculated using RADTRAN for the same conditions and distances from the source, and shows the essential conservatism of the RADTRAN approximation. Hoskins calculates a total dose to an inspector of 0.0181 mSv (1.81 mrem) for a 45-minute (0.75 hour) inspection, which is consistent with the doses calculated by RADTRAN in Figure 2. RADTRAN calculations for the Newport News fuel yield a 45-minute inspection dose of 0.0842 mSv (8.42 mrem).

Figure 2 compares the dose rate calculated by RADTRAN using the dose one meter from the surface as measured by Hoskins with the dose rate map given by Hoskins, and shows the overestimate of the dose rate given by RADTRAN. The overestimate probably occurs because the package shape factor (K) in Equation (1) is probably not a constant, as in the equation used, but a function of distance from the package. The package shape factor will be addressed in a future edition of RADTRAN. It may be noted that the package shape factor appropriate for the TN-8L cask in the Hoskins study is slightly larger than that for the Newport News container.

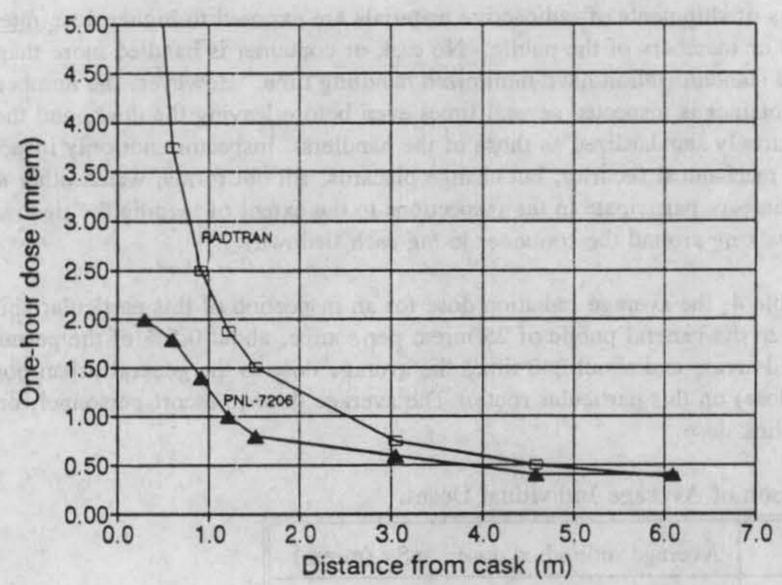

Figure 2. Comparison of the near-field dose rate calculated by RADTRAN with that from the dose rate map given by Hoskins, et al (PNL-7206).

What is the function of inspections? Even the first inspection of a cask or container entering the United States by sea will be at least the second radiological inspection that the container will have undergone since it was prepared for shipment. The results of the initial inspection (when the container was loaded) are entered on the shipping papers. The purpose of the USCG inspection at the port of entry is to verify the initial radiological inspection. Subsequent inspections are presumably intended to confirm the USCG inspection. However, they would be made only if the USCG inspection confirms the initial inspection, which in turn must have been a maximum dose rate within regulatory limits; that is, if a dose rate deviated significantly from that recorded on shipping papers during offloading at the port, a different set of protocols will apply, and the container would not be transported, as is, further in the continental U.S. nor undergo further inspections by non-federal personnel. If the results of initial inspection are confirmed by the USCG inspection, further inspections in the absence of any transportation incident or accident can only reconfirm the initial dose rate, but could compound any calibration errors and unnecessarily expose the inspectors themselves.

"Cask weeping" can result in external contamination and can thus cause a discrepancy between the surface dose rate recorded at the shipment origin and that recorded at a port of entry. Detection of contamination due to "cask weeping" on inspections after the first destination inspection (second inspection) when it had not been observed during the first destination inspection is highly unlikely. Recently, a cask shipment from India arrived at Dounreay, Scotland, with a low level of external contamination due to "weeping." The contamination was detected immediately on arrival at Dounreay, i.e., on the first destination inspection and the second inspection overall (Wilkinson, 1991).

Multiple inspections result in sufficient exposure to inspectors to invoke ALARA considerations. There does not appear to be any offsetting benefit in radiological protection of the general public.

Doses to Escort Personnel

Doses to escort personnel appear to be comparable to the average off-link dose. Thus, ALARA considerations would not play a part in regulating escort services. However, the purpose and benefit of an escort through rural areas is not clear. The same escort provisions ought to apply to transportation of radioactive material as apply to any oversize vehicle on the road.

REFERENCES

Hoskins, C. J., et al., *Time/Motion Observations and Dose Analysis of Reactor Loading, Transportation, and Dry Unloading of an Overweight Truck Spent Fuel Shipment PNL-7206*, Pacific Northwest Laboratories, Richland, WA (1992)

Neuhauser, K. S., and F. L. Kanipe, *RADTRAN 4: Technical Manual, SAND89-2370 (TTC-0943)*, Sandia National Laboratories, Albuquerque, NM, in preparation (1992).

Neuhauser, K. S., and R. F. Weiner, *Intermodal Transfer of Spent Nuclear Fuel at United States Ports, SAND91-1903 (TTC-1087)*, Sandia National Laboratories, Albuquerque, NM, in preparation (1992).

Title 10 Code of Federal Regulations, Part 20, Office of the Federal Register, Washington, DC (1991).

Title 10 Code of Federal Regulations, Part 71, Office of the Federal Register, Washington, DC (1991).

Title 10 Code of Federal Regulations, Part 73, Office of the Federal Register, Washington, DC (1991).

Title 40 Code of Federal Regulations, Part 191, Office of the Federal Register, Washington, DC (1991).

Title 49 Code of Federal Regulations, Part 173, Office of the Federal Register, Washington, DC (1991).

Wilkinson, Helen, SRD, UK, personal communication, September 1991.