The Risks and Consequences from the Transport of Low Specific Activity Materials by Truck*

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INTRODUCTION

The packaging and transport category of low specific activity (LSA) material was conceived for radioactive materials (RAM) that were considered inherently safe for transport. Such materials could be transported in "strong, tight" packages. The primary concern for the radionuclide content in LSA materials was associated with the potential for inhalation of particulate radioactive material. Thus, the specifications for the category in terms of specific activity were structured to preclude excessive inhalation hazard.

The current version of the International Atomic Energy Agency (IAEA) regulations maintains the inhalation-related limits but also shows concern that the restrictions on the LSA category may not preclude an excessive external radiation hazard for gamma-emitting materials. This paper presents the results of an investigation of the potential for such excessive external radiation hazards, particularly for LSA materials with specific activity levels near the current regulatory limit (Ostmeyer et al 1988). This paper discusses analyses that were performed to evaluate the potential radiological impacts of highway accidents leading to the release of high radiation level-low specific activity (HRL-LSA) materials from their packagings. The results of the analyses are intended to provide a basis for evaluating restrictions on the quantity of gamma-emitting radionuclides that can be contained in an LSA shipment.

Consequences of a very severe accident were estimated to gauge the relative impact of three potential LSA specifications:

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1. The current regulatory restriction on specific activity (0.3 millicuries per gram per radionuclide).

2. The specific activity consistent with a package dose-rate restriction of 1 rem/hr at 3 m from the package.

3. The specific activity consistent with a package dose-rate restriction of 1 rem/hr at 1 m from the package.

A risk analysis, using a spectrum of LSA shipments consistent with current shipping levels, was performed to demonstrate the level of risk of HRL-LSA shipments compared with all other LSA shipments and to compare with other analyses involving estimation of risk.

LSA SHIPMENT DESCRIPTIONS

Spent Resins

Spent ion-exchange resins from nuclear reactor facilities generally have the highest specific activity levels of all LSA materials and are considered specifically in this report. Because these resins hold significant gamma-emitting radionuclides, they pose the greatest external exposure hazard.

Synthetic ion-exchange resins having a basic structure composed of polystyrene and divinylbenzene are used most frequently in the nuclear industry. A strong acid cation exchanger with the sulfonic acid functional group in the H^+ form and a strong base anion exchanger with quaternary ammonium in the OH^- form are used most often. Resins are generally used as supplied by the manufacturers with no additional pretreatment. Bead resins are used most frequently at both pressurized and boiling water reactor facilities. These ion-exchange resins, even when dewatered for shipment after use, have a water content of approximately 50%, but this may vary by $\pm$20%. The moisture retained by ion-exchange resins is mostly water of hydration not free water. The water content of the resins is a very important factor in their combustibility.

Virtually all spent ion-exchange resins are shipped and disposed of in 55-gallon drums or in larger steel cylinder (liners) which fit closely inside shielded containers. Based on information in Colton et al 1981, liners contain the majority of the total radioactivity (>90%), but account for less than 40% of the spent resin volume and less than 20% of the spent resin containers.

For calendar year 1980, Colton found that large waste liners containing spent ion-exchange resins accounted for about 3% of the total LSA packages shipped to low-level waste repositories. However, these large liners were found to contain about 50% of the total curies of radioactive material. The overall mean specific activity for all spent resins transported in 1980 was approximately 0.0032 mCi/g. This is nearly two orders of magnitude less than the limit specified in 49CFR173 for gamma-emitting radionuclides (0.3 mCi/q). The specific activity for resins shipped in large liners, however, was higher than for resins shipped in 55-gallon drums. The mean specific activity levels were 0.00034 mCi/g for material in 55-gallon drums, 0.0076 mCi/g for liners with a volume between 10 and 90 ft^3, and 0.0075 mCi/g for larger liners. The larger resin liners are considered to be characteristic of those addressed in this paper. The major radionuclide contributors for HRL-LSA resin waste shipments, as derived from information in Colton et al 1981 were: Co-60 (~29%), Cs-137 (~20%), Zn-65 (~11%), Cr-51 (~10%), Cs-134 (~9%), Co-58 (~8%), Mn-54 (~3%).

HRL-LSA resin in drums or liners is shipped in lead-shielded containers which are classified as Type A shipping casks. Most certified shipping casks are of heavy lead and steel construction and utilize an upright cylindrical design (USNRC 1985). The quantity of spent resin in a shipment is limited generally by the requirement for radiation shielding, which assures that the shipment satisfies the radiation level limitations for the outer surface of the cask, for areas external to the conveyance, and for drivers of the vehicle on which it is carried (49CFR173.441).

Recent Shipping Data

Data (Chem Nuclear 1986) for the Barnwell waste disposal site were examined and grouped according to specific activity range and number of packages per shipment. Single package (SP) shipments are assumed to be only large liners in a single package per shipment, while multiple package (MP) shipments are assumed to contain mixed LSA wastes (both hazardous and radioactive materials present) with multiple packages per shipment. Specific activities for both SP and MP shipments were grouped into five ranges: Shipment 1 ($\geq$ 0.02 mCi/g); Shipment 2 ($\geq$ 0.002 mCi/g but < 0.02 mCi/g); Shipment 3 ($\geq$ 0.0002 mCi/g but < 0.002 mCi/g); Shipment 4 ($\geq$ 0.00002 mCi/g but < 0.0002 mCi/g); and Shipment 5 (< 0.00002 mCi/g). Radionuclide inventories for SP and MP shipments differ because of the origins of the wastes (e.g., hospitals tend to use drums, i.e., MP, while energy production facilities tend to ship single liners (SP)). Thus, radionuclides such as tritium (H-3) appear in the MP shipments but not in the SP shipments. These shipments and their characteristics were used in the risk assessment. In addition to the data derived from Chem Nuclear 1986, the bounding cases from the consequence-only analysis were included in the risk analysis.

ANALYSIS OF POSTULATED ACCIDENTS

Consequence Only Analysis

The Radioactive Material Transportation Accident/Incident Data Base (RMIR) (Emerson and McClure 1983) was used to identify highway accidents involving Type A shipping casks. As of November 1985, eight reports of highway accidents involving such casks were contained in RMIR. None of the reports indicated a release of any radioactive material. The fact that no releases occurred is significant since five of the eight accidents involved overturning of the cask, or of the cask and trailer, that could have led to severe impact stresses on the containers. Seven of the reports indicated that the accident occurred on sections of highways that are in areas classified as rural. Of these, four occurred on two-lane highways and three on divided highways. Only one occurred on a route segment in an area classified as urban.

Stress and failure mode analyses for typical Type A shipping casks were performed to develop a scenario for the worst case consequence calculations. In addition, both theoretical calculations and bench-scale experiments on the burn characteristics of ion-exchange resins were performed prior to developing analysis scenarios. The results of these analyses and experiments are reported in detail in Ostmeyer et al 1988.

Risk Analysis

The results presented in this paper for accidents involving HRL-LSA and other LSA shipments were calculated with the RADTRAN III computational system (Madsen et al 1986), by application of a method described in Neuhauser and Reardon 1986. The essential components of the RADTRAN III system are:

* a material model to define the radionuclide specific characteristics;
* a transport model to describe accident rates, traffic patterns, mode-specific shipment information;
* two geometric models, developed specifically for the current analysis, to accurately estimate the dose rate at the surface of a transport vehicle;
* an accident severity model to specify ranges for the seriousness of transport accidents involving RAM;
* a release fraction model to represent the portion of package contents exposed in an accident;
* a package release model to determine the expected release fraction for each radionuclide in various population zones
* a population distribution model for various areas along a "generic" transport route;
* a health effects model to quantify potential health related impacts of exposure of local populations to released radionuclides;
* an economic model to provide order-of-magnitude cost estimates for cleanup following accidents; and
* a radionuclide impact model to compute the effect of vehicular accidents in terms of level of consequence, probability of occurrence, and potential risk.

A travel distance of approximately 1100 km (720 mi) was assumed for the spent resin shipments, while for multiple package shipments, the travel distance was assumed to be approximately 1000 km (630 mi).

RADIOLOGICAL IMPACTS

Exposures were divided into 2 categories. These are: close-proximity and population doses. The close-proximity category, developed for the current analysis, includes exposures to the truck driver or drivers, to individuals in other vehicles that might be involved in the accident, and to individuals responding to the accident. Individuals responding to an accident may include police or highway patrol officers, fire engine crews, paramedics, and ambulance attendants.

The magnitude of a close-proximity dose can vary widely depending on distance from a postulated spill, degree of radiation shielding, and duration of exposure.

Because of the variability in dosimetric parameters, it is not possible to define a maximum dose that an exposed individual might receive. Results for close-proximity exposures are presented in terms of the exposure times required to receive selected radiation doses at the edge of a 9 m (30 ft) radius spent resin spill (Table 1).

For a distance of 20 m (66 ft) from the edge of a 9 m (30 ft) radius spent resin spill, the times required for an individual to receive specified radiation doses are factors of 10 to 100 times longer.

Population doses were calculated for four different accident locations: a rural two-lane highway, a rural four-lane highway (an interstate highway), a six-lane suburban freeway, and a ten-lane urban freeway. Table 2 presents the results for a mixed release of typical radionuclides for the four locations.

In addition to estimates of direct gamma population dose, RADTRAN III consequence calculation of population exposures resulting from a burn of 1 kg, 10 kg, and 100 kg of spent resin were performed to evaluate the effects of aerosolization of significant quantities of the radionuclides contained within spent resins. The rural population dose resulting from aerosolization of spent resin at the current LSA limit would not exceed 30 person-rem, even for the most conservative case involving combustion of 100 kg of spent resin. The estimated rural population doses for combustion of 10 kg of resin are 3.7 person-rem for the current regulatory limit, 0.5 person-rem for the 1 rem/hr at 3 m dose-rate restriction, and 0.09 person-rem for the 1 rem/hr at 1 m dose-rate restriction. The population doses for accidents in suburban and urban areas are estimated to be substantially larger than for accidents in rural areas. Nearly all of the population doses reported result from groundshine, and are more than two orders of magnitude larger than the internal radiation doses resulting from inhalation of radionuclides.

Table 1
Exposure Times Required to Receive Selected Radiation Doses at the Edge of a 9 m (30 ft) Radius Spent Resin Spill

Restriction on Specific Activity	External Dose*		
	50 Rem	5 Rem	0.5 Rem
Current Regulations:	2.2 hr	13 min	1.3 min
1 rem/hr at 3 m:	20 hr	2 hr	12 min
1 rem/hr at 1 m:	130 hr	13 hr	1.3 hr

*In Ostmeyer et al 1988, results were calculated using more than one initial source term. The results presented here were for a mixed release of typical radionuclides, characteristic of those present in HRL-LSA wastes.

Table 2
Estimates of Direct Gamma Population Dose for Postulated Accidents Involving Spent Resin that Contains a Mixed Radionuclide Loading
(Dose Per Shipment)

Type of Roadway	Total Population Dose (person-rem)		
	Current Reg. LSA Limit	1 rem/hr at 3 m	1 rem/hr at 1m
Two-Lane Rural Highway	70	7	1.3
Four-Lane Rural Highway	100	10	1.7
Divided Six-Lane (Suburban)	170	18	3.1
Divided Ten-Lane (Urban)	100	11	1.9

Risk Evaluations

Incident-free radiological risk, calculated using RADTRAN III, for a year of shipping activity at the level reported in Chem Nuclear 1986 would be approximately 600 person-rem (0.1 LCF). This result compares with an estimated incident-free risk level from USNRC 1977 for mixed fission and corrosion products of approximately 6,000 person-rem (1.2 LCF). Refinements in the modeling and shipment data account for the observed differences.

Accident risk results were strongly dependent on the postulated release and aerosol fractions. The values for these parameters, used in this analysis, are considered upper bounds to actual values for Type A casks and LSA packagings (Neuhauser and Reardon 1986). Without more information on the response of Type A packages to accident environments, the reported accident risks are also considered upper bounds. The total potential accident radiological risk for a year of shipping activity at the level reported in Chem Nuclear 1986 is estimated to be approximately 110 person-rem (0.02 LCF). The comparable value from USNRC 1977 is approximately 15 person-rem (0.003 LCF), where sizeable shipments in Type A casks were not addressed specifically.

The potential risk per year from the shipment of LSA materials is estimated to be approximately 670 person-rem (0.12 LCF). This is compared with the potential exposure from one maximum accident involving spent resin HRL-LSA material, where the consequences are estimated at approximately 160 person-rem (0.03 LCF).

CONCLUSION

The following observations can be made from the work presented here and in Ostmeyer et al 1988:

1. The quantity of gamma-emitting radionuclides in a shipment is limited by current shipping requirements and practices to levels below the current regulatory limit. Most shipments of LSA material will contain less than 1,000 Ci of gamma-emitting radionuclides, even in the extreme.

2. Dose-rate restrictions for unshielded LSA containers reduce the maximum number of curies transported and the average specific activity per shipment. For a large LSA waste liner, the dose-rate restriction of 1 rem/hr at 3 m could reduce the maximum specific activity permitted by nearly an order of magnitude from the current regulatory level. The dose-rate restriction of 1 rem/hr at 1 m could further reduce the maximum activity level by a factor of 5. Both restrictions would increase the total number of shipments. The package dose-rate restriction of 1 rem/hr at 3 m would impact about 4% of the current LSA waste shipments (approximately 250 shipments/year). However, because of the extent to which the LSA material would have to be diluted and/or divided into available Type B shipping containers to be shipped in the LSA classification, the restriction could create hundreds to more than a thousand additional shipments per year. The 1 rem/hr at 1 m restriction would impact about 23% of all HRL-LSA shipments and could create thousands of additional shipments per year.

3. Even with the conservative assumptions regarding release and the conservative models used to estimate dose, external radiation doses to an individual as a result of an accident involving a shipment of HRL-LSA material at the current regulatory limit would likely be less than a few tens of rem. Using more realistic assumptions about radionuclide releases, the maximum individual doses for HRL-LSA waste are unlikely to exceed a few rem. The maximum individual external doses from LSA waste for which activities are limited by either of the alternative dose-rate restrictions are likely to be within current radiation exposure guidelines.

4. The population dose for external exposure to a spill is likely to be less than a few hundred person-rem for material shipped at the regulatory limit. The external population doses for resins restricted by package dose-rate are likely to be less than a few tens of rem.

5. Potential population doses from inhalation of aerosolized radionuclides could be greater than the direct gamma dose from a spill. However, because aerosolized radionuclides would be highly dispersed, maximum individual doses for people in areas downwind of the accident site are likely to be substantially less than the maximum external doses at the site. This results from the original concern regarding the inhalation hazard for LSA materials which led to setting the permitted specific activity levels at relatively low values.

Based on the analyses reported, current LSA limitations are sufficient to prevent excessive external radiation exposure to an individual following a severe transportation accident. Package dose-rate restrictions would provide a higher level of confidence that external radiation doses are unlikely to be excessive, but these restrictions could have a substantial adverse impact on shipping practices and costs for transportation of LSA material.

In addition to dose-rate restrictions, other options for changes in the handling of LSA materials such as limiting the A1 and the quantity in package have been proposed. As with the dose-rate restrictions, the "cost" of implementing other options would be either to increase the total number of LSA shipments or increase the overall cost of packaging and transporting the materials.

REFERENCES

Chem Nuclear, Inc., Letter Report to Sandia National Laboratories (LSA Shipment Data), 1986.

Colton, J. D., et al, "Transport of Low Specific Activity Materials," NUREG/CR-2440, SRI International, Menlo Park, CA, 1981.

Emerson, E. L. and J. D. McClure, "Radioactive Material (RAM) Accident/Incident Data Analysis Program," SAND82-2156, Sandia National Laboratories, Albuquerque, NM, 1983.

Madsen, M. M., et al, "RADTRAN III," SAND84-0036, Sandia National Laboratories, Albuquerque, NM, 1986.

Neuhauser, K. S. and P. C. Reardon, "A Demonstration Sensitivity Analysis for RADTRAN III," SAND86-1001, Sandia National Laboratories, Albuquerque, NM, 1986.

Ostmeyer, R. M., et al, "The Potential Consequences and Risks of Highway Accidents Involving Gamma-Emitting Low Specific Activity (LSA) Waste," SAND87-2808, Sandia National Laboratories, Albuquerque, NM, 1988.

U. S. Nuclear Regulatory Commission, "Final Environmental Statement On the Transportation of Radioactive Materials by Air and Other Modes," NUREG-0170, Washington, DC, 1977.

U. S. Nuclear Regulatory Commission, "Directory of Certificates of Compliance for Radioactive Materials Packages, Revision 8," NUREG-0383, Washington, DC, 1985.