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Simulation of Transportation of Low Enriched Uranium Solutions (U)

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SIMULATION OF TRANSPORTATION OF LOW ENRICHED URANIUM SOLUTIONS (U)

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ABSTRACT

A simulation of the transportation by truck of low enriched uranium solutions has been completed for NEPA purposes at the Savannah River Site. The analysis involves three distinct source terms, and establishes the radiological risks of shipment to three possible destinations. Additionally, loading accidents were analyzed to determine the radiological consequences of mishaps during handling and delivery.

Source terms were developed from laboratory measurements of chemical samples from low enriched uranium feed materials being stored at SRS facilities, and from manufacturer data on transport containers. The transportation simulations were accomplished over the INTERNET using the DOE TRANSNET system at Sandia National Laboratory. The HIGHWAY 3.3 code was used to analyze routing scenarios, and the RADTRAN 4 code was used analyze incident free and accident risks of transporting radiological materials. Loading accidents were assessed using the Savannah River Site AXAIR89Q and RELEASE 2 codes.

INTRODUCTION

Low enriched uranium (LEU) solutions stored at the Savannah River Site (SRS) are being studied in preparation for shipment to an off-site processor. The radiological risks of transporting these solutions off-site are evaluated for three uranium enrichments (0.274%, 0.7%, 2%), and three distinct destinations (Portsmouth, VA; Johnson City, TN; and Kingsville, TX). The present analysis and the environmental assessment of the shipment process are important to support the decision that is being made to outsource the processing of the LEU solutions.

Simple source term calculations using truck cask capacity, measured radioactive concentrations, and laboratory isotopic analysis were completed. The HIGHWAY 3.3 [1-2] and RADTRAN 4 [3-4] computer codes are used to analyze transportation accidents and incident free travel. The HIGHWAY 3.3 is used to determine highway mileage and population densities from SRS to each of the three destinations considered. Using the results of HIGHWAY 3.3, and the source term calculations, the RADTRAN 4 code is used to evaluate the risks associated with transporting 17,500 liters of LEU solution over the specified routes. In addition, a loading accident at SRS was analyzed using the site developed AXAIR89Q and RELEASE2 codes for radiological consequences to on-site and off-site receptors. The analysis assumes a loading accident where 15,000 liters of 2% enriched uranium solution is spilled on the ground at SRS.

CALCULATIONAL METHODS

Source Terms

Source terms were developed for a tank truck containing 17,500 liters of low enriched uranium solution in three cases: 2% enrichment, 0.7% enrichment, and 0.274% enrichment in U-235. Table 1 shows the source terms used in the calculation. The activity of all isotopes other than Uranium and Plutonium were consolidated as Cs-137. Since no specific isotopic breakdown of 0.274% enriched uranium solution was available, it was assumed to be equal to the isotopic content of the 0.7% enriched solution. RADTRAN 4 requires the input of the external dose rate at 1 meter from the shipping cask. For the purpose of this evaluation the dose rate was assumed to be 0.5 mrem/hr at a distance of one meter, entirely due to gamma radiation. In addition, some source term substitutions were made to account for missing species in the RADTRAN 4 isotope library.

Computer Codes

HIGHWAY 3.3

The HIGHWAY 3.3 code is an automated geographical routing analysis tool that was developed by the U.S. Department of Energy for use with shipping radioactive materials by truck. HIGHWAY 3.3 is maintained on the Sandia National Laboratory TRANSNET computer system by Oak Ridge National Laboratory. The code is has been benchmarked against other available transportation codes. The HIGHWAY 3.3 database describes over 240,000 miles of national, state and local freeways and roads. Computation of routes is an algorithm that minimizes total impedance, which is a function of distance and driving time between origin and destination. Input to Highway 3.3 consists of entering the beginning and ending points of the shipment, and whether or not a sole use vehicle will be utilized. System defaults may also be changed. For this analysis all system defaults were kept at their original default. These defaults generate routes based on US Department of Transportation routing regulations. The HIGHWAY 3.3 was used to determine highway mileage and population densities from SRS to each of the three destinations considered: Portsmouth, VA; Johnson City, TN; and Kingsville, TX.

RADTRAN 4

The RADTRAN 4 code is a transportation analysis tool developed by the U.S. Department of Energy to analyze the risks of shipping radioactive materials to workers and the general public. This code calculates radiological doses from incident free shipping of radioactive material and radiological risks from accident conditions. RADTRAN 4 is maintained at Sandia National Laboratory on the TRANSNET computer system. The documentation including a User Guide [3] and a Technical Manual [4] is provided for the software. Input to RADTRAN 4 in this analysis is shown in Table 2. For each of the three possible shipment destinations, the three separate source term strengths shown in Table 1 were analyzed. Pathways analyzed for human exposure include direct exposure from contained material, inhalation and airborne immersion from released material. The analysis did not attempt to quantify risks from agricultural products contaminated as a result of the release of the LEU solutions that may occur under accident conditions. As a result, no calculations were performed to assign risk values to food pathways.

AXAIR89Q

One curie dose conversion factors are required as input to the RELEASE2 code. The AXAIR89Q code was used to calculate facility specific dose conversion factors based on one curie of released radioactive material. Each radionuclide has a dose conversion factor for the ground release pathway resulting from a hypothetical ground release. Dose conversion factors were calculated using 99.5% meteorology data. On-site receptor locations were at 100 meters, 1000 meters, and 2000 meters from the ground release in the worst sector. Off-site receptors were the maximum off-site individual (MOI) in the worst sector and the 50-mile surrounding population. AXAIR89Q uses historical weather observations from 1987-91 including wind speed, direction and stability class to determine the dose conversion factors (DCF).

The AXAIR89Q computer code calculates the effective dose equivalent (EDE) and organ doses resulting from a radioactive release to the atmosphere. The dispersion and dosimetry models employed in the code are those as described in NRC Regulatory Guides 1.145 [5] and 1.109, [6] respectively. AXAIR89Q will calculate doses for both vent and stack releases. Fifty-year dose commitments to individuals and populations are determined as a result of inhalation and direct exposure ("cloud shine").

The ground level radionuclide concentration is estimated at given distances from the release point by using a Gaussian plume model. As the plume moves downwind, the radioactive pollutants are assumed to be normally distributed around the central axis of the plume. The diffusion coefficients representing the dispersion of the plume are calculated by using the Pasquill and Gifford model. Plume rise is not considered so the doses are conservatively evaluated.

Five years of meteorological data (1987-1991) are used. The data were obtained by taking hourly averages of meteorological measurements taken at 1.5 second intervals. The meteorological data files include joint frequency distributions and reciprocal average wind velocities that are categorized by wind speed, direction, and stability. The code uses the defined location, stack (release) height and stack base elevation (if any) to calculate downwind radionuclide concentrations and radiological doses.

RELEASE 2

The RELEASE 2 computer code was used to calculate the total curies of radionuclides released through evaporation following an accidental release of radioactive solution into a ground pool. RELEASE 2 is a deterministic, first principles application code that computes the amount of radioactive material being transported into the atmosphere from a liquid pool. Physical phenomena modeled included nuclear heat generation, evaporative heat transfer and vapor pressure differences from an exposed pool of liquid material containing radioactive components. The RELEASE 2 program then uses the database created from AXAIR89Q to compute atmospheric dispersion and doses for the MOI, the on-site receptors at specific distances, and the 50 mile off-site population. The parameters and general assumptions that were used in the RELEASE 2 program for this analysis are shown in Table 3.

RESULTS

The travel distance data calculated with the HIGHWAY 3.3 code are shown in Table 4. The transportation consequence results calculated with RADTRAN 4 are shown in Table 5. As can be seen, the incident free transport radiological consequences are equal for all enrichment levels, since they are determined by assuming a gamma exposure of 0.5 mrem per hour at one meter. The accident risks, however, increase with increasing enrichment level, since they were determined by the curie content of material dispersed. Also, as expected, the longer the distance traveled, the higher the radiological consequences and risks.

The results show that the maximum incident free doses to the worker and the public occur for LEU solution shipped from SRS to Kingsville, TX. The risk to the public from the maximum accident is equal to 2.02 person-rem per shipment. This dose is distributed among a calculated population of 2.65E+06 persons along the route who will have a background radiation population dose of approximately 7.95E+05 person-rem per year.

The one curie dose conversion factor results calculated with AXAIR89Q are shown in Table 6. The maximum accident consequences calculated with the RELEASE 2 code are provided in Table 7 for the 15,000 liters of LEU solution with an enrichment of 2% in U-235 spilled on the ground at SRS.

The results show that U-232 and Pu-239 yield the largest doses per curie released. However, the major contributor to the dose is U-234 since this isotope is the most abundant in the source term considered, and has a nearly equivalent one curie dose conversion factor when compared to U-232 and Pu-239. The results listed in Table 7 show that total doses are equal to 1.46E-01 mrem for the MOI and 7.56E-01 person-rem for the off-site population. The on-site individual dose at 100 meters from the spill is 7.72E+01 mrem, and decreases to 1.49E+00 and 8.23E-01 mrem at distances of 1000 meters and 2000 meters, respectively.

CONCLUSION

Simulation of the safe transportation of LEU solutions requires knowledge of the radiological consequences during normal transportation and the risks associated with transportation accidents. This paper has shown that the radiological doses from incident free shipment and the radiological risks from transportation accidents involving LEU solutions being shipped from SRS could be adequately determined using an appropriate computer code package. Included in this package are the HIGHWAY 3.3 code, the RADTRAN 4 code, the AXAIR89Q code and the RELEASE 2 code. In addition, this computer code package was found appropriate for evaluating the off-site and on-site radiological doses due to a hypothetical loading accident where LEU solution is spilled onto the ground at SRS.

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Table 1. Source Terms for Low Enriched Uranium Solutions

Isotope	0.274% Enrichment Ci/Shipment	0.7% Enrichment Ci/Shipment	2% Enrichment Ci/Shipment
U-232	7.64E-03	1.31E-02	2.80E-02
U-233	1.72E-02	2.96E-02	6.34E-02
U-234	1.66E+00	2.86E+00	5.25E+00
U-235	3.71E-02	6.38E-02	9.64E-02
U-236	2.96E-01	5.09E-01	1.05E+00
U-238	8.26E-01	1.42E+00	7.36E-01
Pu-239	4.57E-03	7.86E-03	4.16E-03
Cs-137*	2.01E-02	3.46E-02	7.07E-02
total	2.870E+00	4.935E+00	7.298E+00

*Note: All remaining activity assumed to be Cs-137

Table 2. Input Data for RADTRAN 4

RADTRAN 4 Input Variable	Supplied Value
Transport Mode	Truck
Material Dispersion Category	Liquid
Packages per Shipment	1
Number of Shipments	1
Transport Index *	0.5
Fraction of Gamma Radiation	1
Length of Package	3.68 meters
Isotopes in Package	See Table 1
Activity in Package	See Table 1
Distance Traveled	See Table 4
Fraction of Travel in Population Zone	See Table 4
Accident Severity Categories (ref. 4)	8
Accident Rates (ref. 3)	1.37E-7 rural
	3.00E-6 suburban
	1.60E-05 urban

* defined as the external dose in mrem/hr at 1 meter

TABLE 3. Input Data for RELEASE 2

RELEASE 2 Input Variable	Supplied Value
Temperature (^{o}C)	40
Heat Capacity (cal/g ^{o}C)	0.84
Recovery Time (hrs)	24
Mass Spilled (kg soln.)	16,680
Total Curies	7.3
Total Mass (kg soln.)	16,680
Radionuclides of interest	See Table 1
Partition Factor	1.0E-04
Filter Penetration Factor	1.0
Composition of Solution	50 % HNO_3, 50 % H_2O, 0% Organic

Table 4. HIGHWAY 3.3 Travel Distance for Off-Site SRS LEU Solution Shipment

Destination	Total Distance (km)	Percent of Travel Rural	Suburban	Urban
Portsmouth VA	717.7	72.6	26.8	0.7
Johnson City TN	436.1	68.4	29.5	2.1
Kingsville TX	1910.2	73.2	24.3	2.5

Table 5. Transportation Consequences and Risks for LEU Solutions Stored at SRS

	SRS to Portsmouth			SRS to Johnson City			SRS to Kingsville		
	Incident Free Dose		Accident Risk	Incident Free Dose		Accident Risk	Incident Free Dose		Accident Risk
	Worker	Public	Public	Worker	Public	Public	Worker	Public	Public
2%	8.82E-04	2.75E-02	5.44E-01	5.64E-04	2.72E-02	4.25E-01	2.38E-03	2.90E-02	2.02E+00
0.7%	8.82E-04	2.75E-02	3.65E-01	5.64E-04	2.72E-02	2.85E-01	2.38E-03	2.90E-02	1.35E+00
0.264%	8.82E-04	2.75E-02	2.12E-01	5.64E-04	2.72E-02	1.66E-01	2.38E-03	2.90E-02	7.87E-01

Note: Dose and Risk units are person-rem per shipment

Table 6. AXAIR89Q 1 Curie DCF for Ground Release

NUCLIDE	MAX OFFSITE INDIV. mrem	ONSITE INDIV@100m mrem	ONSITE INDIV@1000m mrem	ONSITE INDIV@2000m mrem	OFFSITE POP man-rem
CS-137	8.47E-02	4.49E+01	8.63E-01	4.77E-01	4.39E-01
U-232	1.77E+03	9.40E+05	1.81E+04	9.98E+03	9.19E+03
U-233	3.44E+02	1.82E+05	3.51E+03	1.94E+03	1.78E+03
U-234	3.44E+02	1.82E+05	3.51E+03	1.94E+03	1.78E+03
U-235	3.18E+02	1.68E+05	3.24E+03	1.79E+03	1.65E+03
U-236	3.18E+02	1.68E+05	3.24E+03	1.79E+03	1.65E+03
U-238	3.18E+02	1.68E+05	3.24E+03	1.79E+03	1.65E+03
PU-239	1.35E+03	7.15E+05	1.38E+04	7.60E+03	6.99E+03

Table 7. Consequences of LEU Solution Loading Accident

NUCLIDE	MAXIMUM OFFSITE INDIV. (MOI) mrem	ONSITE INDIV @100m mrem	ONSITE INDIV @1000m mrem	ONSITE INDIV @2000m mrem	OFFSITE POPULATION man-rem
CS-137	3.53E-07	1.87E-04	3.59E-06	1.99E-06	1.83E-06
U-232	2.92E-03	1.55E+00	2.99E-02	1.65E-02	1.52E-02
U-233	1.28E-03	6.79E-01	1.31E-02	7.24E-03	6.64E-03
U-234	1.06E-01	5.62E+01	1.08E+00	5.99E-01	5.50E-01
U-235	1.80E-03	9.53E-01	1.84E-02	1.02E-02	9.36E-03
U-236	1.96E-02	1.04E+01	2.00E-01	1.11E-01	1.02E-01
U-238	1.38E-02	7.28E+00	1.40E-01	7.76E-02	7.15E-02
PU-239	3.30E-04	1.75E-01	3.37E-03	1.86E-03	1.71E-03
Total:	1.46E-01	7.72E+01	1.49E+00	8.23E-01	7.56E-01