Radiological Impact on the Public of Transportation for the Canadian Nuclear Fuel Waste Management Program

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INTRODUCTION

In 1978 the Federal Government of Canada agreed on a joint program with the Province of Ontario to assure the safe and permanent disposal of used fuel waste from power reactors. Disposal system concept assessment documents prepared by Atomic Energy of Canada Limited (AECL) and Ontario Hydro will be submitted in early 1991 for review by an Environmental Assessment Panel, under the Federal Environmental Assessment Review Process.

This paper describes the radiological assessment of the transportation component of the disposal system, considering potential impacts on the public in both normal and accident conditions. Data were developed for three alternative reference repository locations, and for three alternative modes of transport. The Used Fuel Transportation Assessment does not aim to compare the alternatives, but rather to assess if used fuel transportation can be carried out acceptably for each of the cases.

TRANSPORTATION SYSTEM

Until such time as a decision is made whether to reprocess or dispose of used fuel, fuel will continue to be stored at Ontario Hydro's CANDU nuclear generating stations. These stations are located on the Great Lakes, and are accessible by road, rail and water. All three modes of transport are being considered in the concept assessment. The destination of the shipments, since a specific site location has not been selected, is assumed to be a generic disposal centre in one of three regions (Southern, Central and Northern) of the Canadian Shield in Ontario, with shipment distances (by road) of 400, 900 and 1900 km. Approximately 180,000 CANDU fuel bundles (about 3600 te U) will be shipped each year.

A detailed transportation system description has been developed for each of the three modes (Shetler 1986) as a basis for analysis of logistics, costs and environmental impacts. The road system is based on a tractor/trailer/cask system designed by Ontario Hydro (Ribbans 1988). A Type B(U) design approval certificate for the cask was received from the Atomic Energy Control Board in July 1987, licensing it to carry up to 192 CANDU fuel bundles at ten years' cooling following discharge from a reactor. The cask is solid stainless steel, almost cubical in shape and has a stainless-steel-sheathed, redwood, impact limiter bolted to the lid, protecting the seal area from impact and fire. Transport is with a dry (air-filled) cavity. The fuel is contained in two irradiated fuel storage-transportation modules. Based on the existing licensed road cask, a reference rail cask has been developed to the concept stage, accepting six fuel modules. The water mode of transport will use either road casks or rail casks, depending upon the land mode of transport selected to interface with the water system.

A number of test programs were carried out in addition to those required for licensing, providing useful data for the radiological safety assessment. Programs included 'extended' fire testing and a one-seventh scale test simulating impact by a locomotive coupler.

METHODOLOGY AND DATA

The methodology used in the radiological assessment was based on the models developed in the US Nuclear Regulatory Commission's Final Environmental Statement (FES) on the Transportation of Radioactive Material by Air and Other Modes (USNRC 1977), and incorporated in the US computer code RADTRAN (Madsen et al. 1986), and in the IAEA-sponsored code INTERTRAN (Ericsson and Elert 1983).

Normal Transportation

The code INTERTRAN was used for the calculation of collective doses in normal conditions. The data required for INTERTRAN were derived separately for each mode-destination case, using the average of several real routes. Some of the data are shown in Table 1. Other data, such as road widths, are built into INTERTRAN.

Individual doses are not given by INTERTRAN, and these were calculated separately using the INTERTRAN exposure models.

Accident Conditions

For accident conditions, the spectrum of possible accidents was divided into a number of categories according to the severity of the impact and thermal environment experienced by the shipment. The accident severity categorization scheme used in the assessment is shown in Figure 1. Accidents in severity categories 1, 1a and 1b do not result in any release of radioactivity.

TABLE 1. DATA REQUIRED FOR ASSESSMENT OF NORMAL CONDITIONS: ROAD MODE, SOUTHERN DESTINATION

Parameter	Zone: Urban	Zone: Suburban	Zone: Rural
Population density ($p.km^{-2}$)	922	370	19
Fraction of travel in zone	0.024	0.05	0.926
Shipment speed ($km.h^{-1}$)	15	50	85
Number of one-way vehicles per hour	153	215	75
One-way distance (km)		400	
Number of shipments		938	
Stop time per 24 hours (h)		6.7	
Number of people exposed at stops		25	
Exposure distance (m)		20	
Pedestrian density factor		6	
Fraction of urban travel on city streets		0.76	
Fraction of rural and suburban travel on freeways		0.07	
Fraction of travel during rush hours		0.15	
Persons per vehicle		2	
Transport index		4.4	

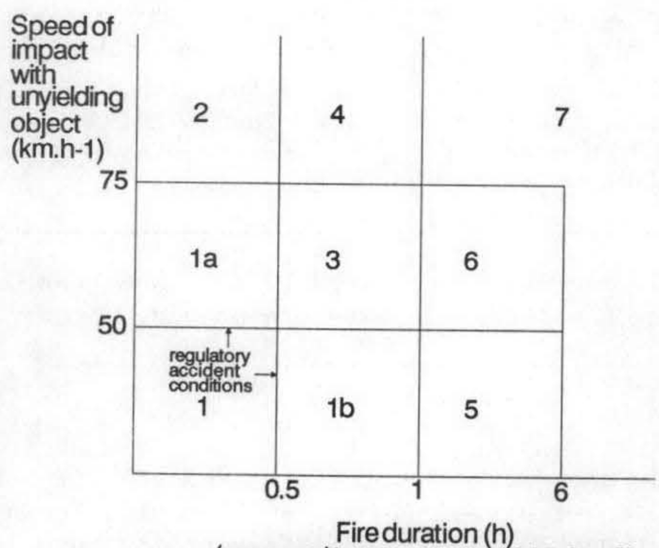

Figure 1. Accident Severity Scheme

The failure boundaries (i.e., impact equivalent to 75 $km.h^{-1}$, or fire duration greater than 1 h), were derived from the cask design program, together with review of the literature on fuel cask design and testing. Potential cask failure modes envisaged for the purpose of this analysis were as follows:

(a) Loss of integrity of the elastomeric lid, vent or drain seals due to thermal degradation in severe thermal conditions.

(b) Loss of lid bolt tension, leading to seal bypass leakage, following a severe impact.

Puncture of the 270 mm stainless steel cask body or lid was not considered credible. This is supported by the rail coupler impact test carried out by Ontario Hydro, in which the cask survived impact at 104 $km.h^{-1}$ by a locomotive coupler with only superficial scratches. Similarly, loss of all lid bolts leading to ejection of gross quantities of fuel, was not considered credible.

Fuel damage assumptions, based on data on CANDU fuel, were 10% rupture in Severity Categories 3 and 5, 20% rupture in Category 6, and 100% rupture in Categories 2, 4 and 7. The fractional release from the cask in each severity category was calculated using Oak Ridge models (Lorenz 1980; Lorenz 1979), together with recent Canadian data on oxidation (Hunt et al. 1986). Based on Wilmot and McClure (1981), it was then assumed that the particulates, also ^{106}Ru, ^{134}Cs, ^{137}Cs and ^{129}I at temperatures below their volatilization temperatures, would be retained within the cask with an efficiency of 0.95. An example of the fractional releases calculated is shown in Table 2.

Overall accident rates were derived from statistics for each route. The fraction of accidents falling into each severity category was then derived using a simplified form of fault tree analysis. This

TABLE 2. FRACTIONAL RELEASES FROM CASK CALCULATED FOR SEVERITY CATEGORY 7

Nuclide group	Fractional release
Gases (e.g. ^{85}Kr)	0.05
Semi-volatiles (e.g. ^{137}Cs)	0.002
Particulate Fission Products (e.g. ^{90}Sr)	10^{-6}
Particulate Actinides (e.g. ^{241}Am)	10^{-6}

methodology is commonly used to estimate the probability of 'rare events', where little or no historical data are available for those particular events. Conditional probabilities of individual events were derived from statistical accident data and from the literature. The results of the fault tree calculations are summarized in Table 3.

For calculation of the consequences of accidents, and combining the consequences with the probabilities to obtain the annual risk, a spreadsheet program based on the RADTRAN/INTERTRAN models was used. This allowed output of probability-consequence curves and of individual doses. The consequences of nearly 2000 accident scenarios were calculated, each representing a different combination of mode, destination, accident severity category, Pasquill weather stability class and population density.

The scheme for calculation of the consequences of a particular scenario was as shown in Figure 2. First, the seal damage, and damage to the used fuel bundles, was quantified for each severity category. The amount of radioactive material released from the cask was then calculated for each category. Dispersion downwind was calculated using the Pasquill dispersion model. An effective height of release of 100 m was used for Severity Categories 5, 6 and 7, where an extended fire was involved.

The pathways drawn with dotted lines in Figure 2 were examined, and shown to make only a small contribution to doses.

The following pathways were included:

(a) Internal exposure following inhalation of airborne radioactivity.

(b) External exposure to radiation from radioactivity deposited on the ground (groundshine):

    (i) immediately following deposition, and

    (ii) over subsequent days, weeks and years, when weathering and cleanup mechanisms influence the doses received.

(c) Internal exposure following inhalation of radioactivity resuspended from ground deposits.

RESULTS

Normal Transportation

Individual doses due to normal transportation were found to be well below the regulatory limit for members of the public of 5 $mSv.a^{-1}$. The highest figure, 0.39 $mSv.a^{-1}$, was for persons exposed to all the shipments at a truck stop, and could be controlled in practice by

TABLE 3. FRACTION OF ACCIDENTS IN EACH SEVERITY CATEGORY

Severity category	road	rail	water
	Fractional occurrence, given an accident		
1	0.99998	0.99988	0.99999
2	10^{-5}	10^{-4}	0
3	10^{-7}	10^{-6}	10^{-8}
4	10^{-9}	10^{-8}	0
5	10^{-5}	10^{-5}	10^{-6}
6	10^{-8}	10^{-6}	10^{-7}
7	10^{-9}	10^{-5}	10^{-5}
Typical overall accident rate (per vehicle-km)	$1x10^{-6}$	$0.5x10^{-6}$	$3x10^{-6}$

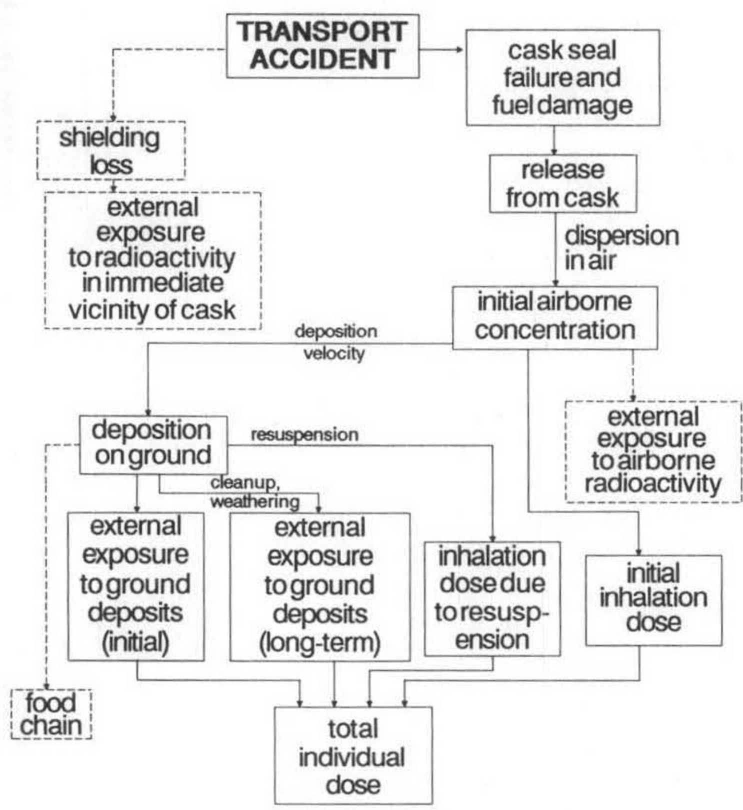

Figure 2. Exposure Pathways

monitoring, use of alternative truck stops, and choice of parking location. The maximum dose of 0.39 $mSv.a^{-1}$ may be compared with the background radiation dose of approximately 3 $mSv.a^{-1}$.

Collective doses calculated were very small, ranging from less than 0.01 $person\text{-}Sv.a^{-1}$ for rail transport, to nearly 0.1 $person\text{-}Sv.a^{-1}$ for road and water-road transport.

Accident Conditions

The maximum individual dose in accident conditions was 34 mSv, for the rail mode, where it was assumed two of the large rail casks could be damaged by an impact (falling) accident. This represents the total dose from all pathways, over a period of 50 a following the accident. The probability of this dose occurring was 10^{-6} a^{-1} or less.

An example of the probability-consequence results obtained for accident conditions is given in Figure 3. This shows the annual probability of a particular collective dose being reached or exceeded, for road transportation to the Southern destination. The maximum collective dose found for any of the cases was about 100 person-Sv, over 50 a.

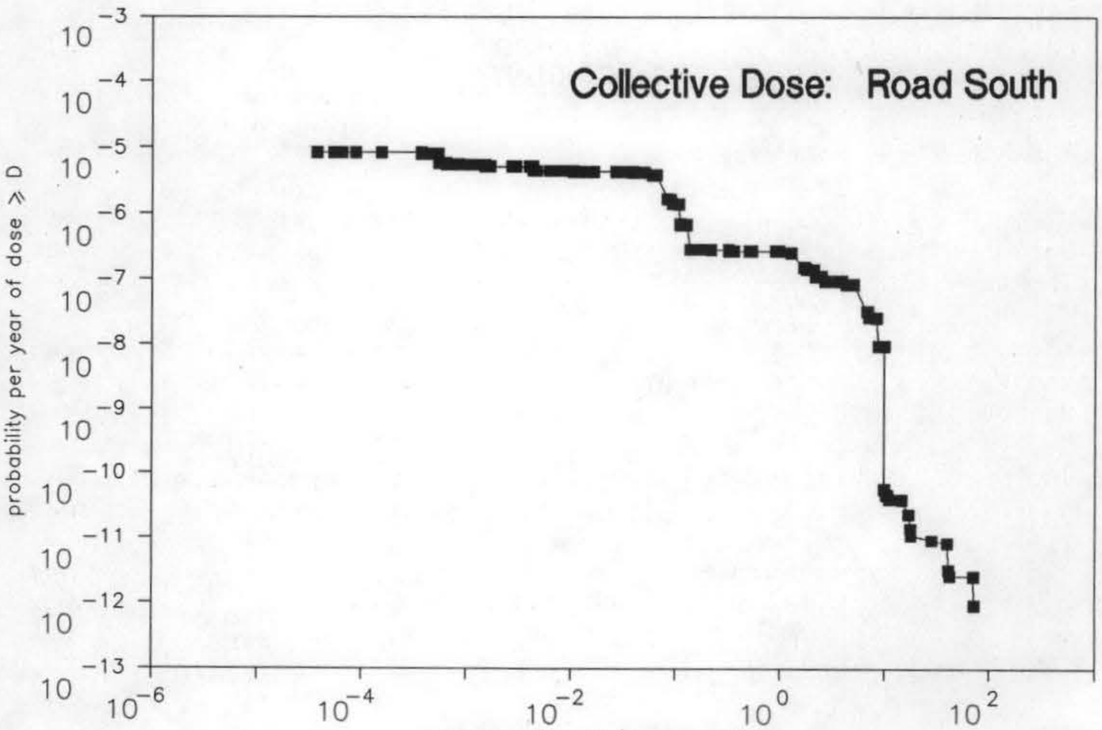

Figure 3. Probability-Dose Curve: Road Mode, Southern Destination

The annual collective risk calculated, i.e., the product of collective dose and probability, summed over all the scenarios, was about 10^{-6} to 10^{-5} person-Sv.a^{-1} for each case.

Conservative parameters were used in the assessment, and these doses may be taken as an upper bound.

REFERENCES

Ericsson, A., and Elert, M. INTERTRAN: A System for Assessing the Impact from Transporting Radioactive Material. IAEA-TECDOC-287 (1983).

Hunt, C.E.L., Iglesias, F.C., Cox, D.S., Keller, N.A., Barrand, R.D., Mitchell, J.R., and O'Connor, R.F. Fission Product Release During UO_2 Oxidation. International Conference on CANDU Fuel, Chalk River Nuclear Laboratories, 6-8 October (1986).
RADTRAN III. SAND84-0036 (1986).

Lorenz, R.A., Collins, J.L., and Malinauskas, A.P. Fission Product Source Terms for the Light Water Reactor Loss-of-Coolant Accident. Nuclear Technology Volume 46, p. 404, Mid-December (1979).

Lorenz, R.A., Collins, J.L., Malinauskas, A.P., Kirkland, O.L., and Towns, R.L. Fission Product Release from Highly Irradiated LWR Fuel. NUREG/CR-0722, ORNL/NUREG/TM-287/R2 (1980).

Madsen, M.M., Taylor, J.M., Ostmeyer, R.M., and Reardon, P.C. RADTRAN III. SAND84-0036 (1986).

Ribbans, D.J. Road Cask for the Transportation of CANDU Irradiated Fuel. International Conference on Transportation for the Nuclear Industry, Stratford.

Shetler, A.P. Systems for Transporting Used CANDU Fuel by Road, Rail, and Water. Second International Conference on Radioactive Waste Management, Winnipeg, September (1986).

USNRC. Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes. NUREG-0170, Volume 2 (1977).

Wilmot, E.L., McClure, J.D., and Luna, R.E. Report on a Workshop on Transportation Accident Scenarios Involving Spent Fuel, May 6-8, 1980. SAND80-2012, TTC-0151 (1981).