An Examination of Environmental Contamination Following a Hypothetical Used-Fuel Transportation Accident

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INTRODUCTION

In October 1994, Atomic Energy of Canada Limited submitted the Environmental Impact Statement (EIS) on the Concept for Disposal of Canada's Nuclear Fuel Waste to the federal environmental assessment panel set up in 1989 to review the concept (AECL 1994). The concept consists of disposal of packaged intact fuel or reprocessing waste 500 - 1000 m deep in granitic rock. No site has yet been selected; in 1981, the governments of Ontario and Canada decided that the concept should be shown to be acceptable before moving to the siting stage. The EIS represents the culmination of over 15 years of research and development by both AECL and Ontario Hydro. Ontario Hydro supports AECL in the development of the concept, and, under the terms of a Provincial-Federal agreement, is responsible for storage and transportation technology.

A previous paper (Kempe and Grondin 1989) described a preliminary public radiological risk assessment carried out for transportation of used nuclear fuel to the disposal site. In the reference transportation system developed by Ontario Hydro, based on a currently-licensed Type B(U) cask, 250 000 bundles per year would be transported a distance of 400 - 1900 km from the nuclear generating stations, mainly located on the Great Lakes, to the reference disposal site somewhere on the Canadian Shield.

The risk assessment has since been revised and expanded for the EIS (Grondin et al. 1994). In addition to the risk assessment, a more detailed examination of potential impacts from ground contamination and surface run-off in the vicinity of a hypothetical accident has been carried out. Contamination levels, areas contaminated, and doses to humans and to non-human biota were calculated. Results from the environmental contamination study are presented in this paper.

OBJECTIVES

An integrated ecosystem approach to environmental impact assessment is endorsed by Ontario Hydro in the Preclosure Assessment (Grondin et al. 1994) carried out for AECL's EIS. This approach involves a broad definition of the environment, including the natural, social, cultural, and economic environments, and recognition of the importance of species other than humans.

In parallel with developments in ecological risk assessment, the assumption commonly made in radiological assessment, that if humans are protected, then other species will also be protected, is being reviewed by national and international bodies.

The present paper represents a step towards development and crystallization of the ecological risk assessment method to be used at the site selection stage of the fuel disposal program.

ACCIDENT SCENARIOS

To keep the environmental contamination study to a manageable scope, two hypothetical accident scenarios were selected from the range used in the risk assessment:

(a) A short term, ground level release of particulates due to a severe impact. This has an estimated annual frequency, for the reference transportation system, of about 10^{-5} and is assumed to result in a fraction 6×10^{-8}, or 1.24×10^{8} Bq of actinides being released.

(b) A prolonged, elevated release of caesium due to an extended, enveloping fire. This has an estimated annual frequency, for the reference transportation system, of about 10^{-7} and is assumed to result in a fraction 4×10^{-3}, or 1.14×10^{13} Bq of caesium being released. The effective height of release was estimated as 100 m.

It should be noted that the frequency of any accident causing a release is very small.

METHODOLOGY

The environmental contamination levels and the size of the contaminated area were estimated for the two scenarios for several weather conditions using standard methodologies (CSA 1987, 1991). Values used for the dry deposition velocity and the scavenging coefficient for wet deposition are shown in Table 1. The dry deposition velocity used is a conservative value for grassland (roughness length 10 cm). The scavenging coefficient used corresponds to either heavy rain or light snow, although the dynamics of deposition in snow and subsequent environmental transfer have not been considered in the present study.

Table 1. Values of Dry Deposition Velocity and Precipitation Scavenging Coefficient

Nuclide Group	Dry Deposition Velocity ($m \cdot s^{-1}$)	Scavenging Coefficient (s^{-1})
actinides	3×10^{-2}	10^{-3}
Cs	3×10^{-3}	10^{-3}

It was assumed that contamination could be washed into local water bodies and result in exposure to aquatic organisms and to humans via drinking water and fish ingestion.

The calculated ground contamination levels were examined, and a representative value selected. The concentrations in environmental compartments, and the doses to humans and to representative non-human biota, were calculated for this value. Use was made of the environmental transfer parameters developed for calculation of food chain doses (Russell 1993). The fall-off in dose rate with time was modelled, for groundshine and resuspension, using empirical models. The results of these models were compared with those from a model describing the reduction in surface concentrations as a result of water infiltration and distribution of radionuclides between soil and groundwater (Russell 1993), with consistent results. The empirical models also compared well with results from measurements of Chernobyl contamination (Reponen and Jantunen 1991). For the food chain, the radionuclide distribution model was used. Removal of radionuclides from water was modelled using sedimentation rates (Russell 1993).

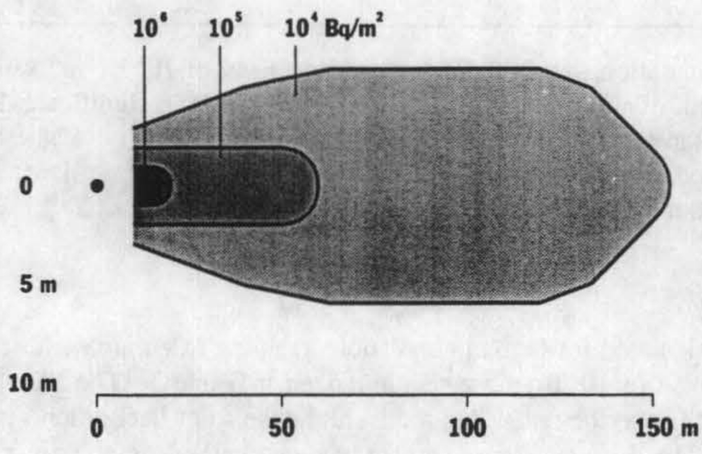
Dose conversion factors for representative non-human biota were taken from studies carried out for the EIS (Amiro 1995, Russell 1993).

RESULTS

Contamination Levels

Isopleths (lines joining points where the surface contaminating level was equal) were plotted for several weather scenarios. A sample isopleth diagram is shown in Figure 1.

Figure 1. Ground Contamination Isopleths for an Actinide Release in Pasquill Stability Class F



The areas within the isopleths, and the percentage of the release deposited within each isopleth, are summarized in Table 2 for the cases considered. All the cases resulted in contamination levels of over 10^4 Bq·m^{-2}. The maximum actinide contamination level was in the order of 10^6 Bq·m^{-2}, while for the Cs release, without precipitation, it was in the order of 10^4 Bq·m^{-2}. However, in the case of the Cs release with precipitation, the maximum contamination level increased to over 10^8 Bq·m^{-2}. The condition assessed, precipitation occurring in stable conditions, would be found very infrequently. In neutral conditions with precipitation, the areas within the isopleths would be similar, but the peak concentration would be lower.

Table 2. Size of Isopleth Areas and Percentage of Release Deposited

Contamination Level Area Percentage of release	Actinides		Cs		
	Stable Conditions	Neutral Conditions	Stable Conditions	Neutral Conditions	Stable Conditions with precipitation
>10^4 Bq·m^{-2}: area (m^2) percentage of release	 10^3 70%	 500 10%	 10^8 40%	 10^7 2%	 10^7 70%
>10^5 Bq·m^{-2}: area (m^2) percentage of release	 200 40%	 25 4%	 -	 -	 6 x 10^6 60%
>10^6 Bq·m^{-2}: area (m^2) percentage of release	 20 20%	 -	 -	 -	 10^6 50%
>10^7 Bq·m^{-2}: area (m^2) percentage of release	 -	 -	 -	 -	 10^5 10%
>10^8 Bq·m^{-2}: area (m^2) percentage of release	 -	 -	 -	 -	 10^3 4%

For subsequent dose calculations, an initial contamination level of 10^4 Bq·m^{-2} was used. This level reflects a judgement of what contamination level may result in significant doses to humans and to non-human biota. It would likely not result in evacuation of the human population, although food interdictions are possible (IAEA 1986); it is similar to levels of Cs ground contamination found in Europe after the Chernobyl accident (OECD 1987).

Doses to Humans

Doses and dose rates calculated for human populations residing in an area with an initial ground contamination level of 10^4 Bq·m^{-2} are summarized in Table 3. The units used are mSv·a^{-1}; for comparison it may be noted that the annual dose from background radiation is approximately 3 mSv. The dose rates are expressed as an annual dose and are given at times of 0 years following deposition and 50 years following deposition. The range in the initial inhalation and cloudshine doses is for the alternatives of wet and dry deposition - with wet deposition, the initial dose is smaller, for a given ground contamination level. The large range for fish ingestion reflects the range between the average consumption of freshwater fish and a high consumption, such as might be found for an aboriginal group (Russell 1993).

The initial doses from inhalation and cloudshine are seen to be small relative to the dose from consumption of produce contaminated by the initial passage of the plume. It may be noted that the ingestion doses for the actinides make use of the higher gut uptake factors published by ICRP (1986). It was assumed in the calculation that the population continues to reside full-time in the contaminated area and that all food and water is produced in the same contaminated area. These are conservative assumptions, particularly for the actinide release, which results in a relatively small contaminated area (which could, nevertheless, for the contamination level of 10^4 Bq·m^{-2}, represent the entire area of a smallholding adjacent to the transportation route).

It is concluded that, even with a level of 10^4 Bq·m^{-2}, monitoring of food and water will be required according to the Ontario Nuclear Emergency Plan (Government of Ontario 1986). With higher levels, doses from resuspension and groundshine may be significant.

Table 3. Annual Doses to Humans for an Initial Contamination Level of 10^4 Bq·m^{-2}

Pathway	Actinides	Cs
Inhalation (mSv)	1	10^{-5} - 10^{-3}
Cloudshine (mSv)	~ 0	10^{-10} - 10^{-8}
Groundshine		
0 a (mSv·a^{-1})	~ 0	0.1
50 a (mSv·a^{-1})	~ 0	10^{-2}
Resuspension		
0 a (mSv·a^{-1})	10	10^{-7}
50 a (mSv·a^{-1})	10^{-3}	~0
Food chain		
initial (mSv)[1]	200	40
50 a (mSv·a^{-1})[2]	1	10^{-4}
Water ingestion		
0 a (mSv·a^{-1})	60	0.2
50 a (mSv·a^{-1})	~ 0	~ 0
Fish ingestion		
0 a (mSv·a^{-1})	200 - 4000	30 - 400

[1] Integrated dose assuming produce contaminated during the initial passage of the plume continues to be consumed, with the contamination level falling with a 12-day half-life.
[2] Ongoing dose due to consumption of food contaminated by root uptake and soil loading.

Non-Human Biota

The potential pathways for exposure of non-human biota are shown in Figure 2. The study takes into account that non-human biota include plants, animals, and microorganisms living in water, sediment, soil, and air as part of aquatic and terrestrial ecosystems. The representative target organisms considered are as follows (Davis et al. 1993):

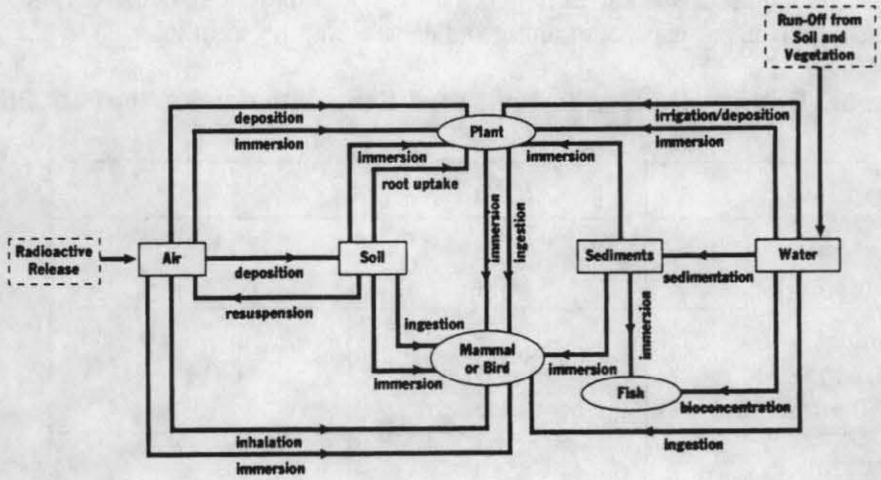
(a) a plant, which may be terrestrial or aquatic;

(b) a mammal, similar to a herbivore in its eating habits, which may be terrestrial, soil-burrowing or aquatic;

(c) a bird, generally representative of terrestrial species, but which is also used to represent waterfowl; and

(d) a fish, representing both free-swimming and bottom-feeding species.

Figure 2. Exposure Pathways for Non-Human Biota



The doses and dose rates calculated for non-human biota are summarized in Table 4. Units of grays, or grays per year, are used. Available quality factors used for weighting human absorbed dose to give equivalent dose in sieverts are based on studies of stochastic effects in humans, and may not be entirely appropriate for non-human biota. Generally, wild species are short-lived compared with humans, and deterministic effects may be most important in terms of effects on viability and well-being. However, as a special case, for this study, the dose from alpha-emitters included in Table 4 have been weighted by a factor 20 to account for the increased biological effectiveness of alpha radiation (Amiro 1995).

The doses in Table 4 may be compared with the dose from natural background radiation, which for non-human biota may range from 0.001 to 0.1 $Gy \cdot a^{-1}$. For a ground contamination level of 10^4 $Bq \cdot m^{-2}$, the doses to the representative non-human biota are smaller than natural background, except for fish. The dose to fish from Cs is about 1 $Gy \cdot a^{-1}$, which may be about the limit for tolerability (Rose 1992, IAEA 1992). Above this level subtle chronic effects might be observed.

CONCLUSIONS

The area potentially contaminated following a very severe transportation accident, and the peak contamination level, would be very dependent on the release scenario and the weather conditions.

Following a very severe accident, monitoring of food and water would probably be required in the long term over a wide area, although it would not be necessary to relocate this population. Cleanup or relocation might be required in a smaller area, particularly if precipitation occurred in the region of the accident.

If the residual contamination levels were low enough that humans were protected, then the natural environment would probably also be protected in the long term. This supports the assumption commonly made in safety analysis. Effects from emergency response and cleanup, which are not detailed in this paper, would probably be the major environmental effect in the short term.

Table 4. Annual Doses to Representative Non-Human Biota for an Initial Contamination Level of 10^4 Bq·m^{-2}

Target Organism Radionuclide	Air Pathways		Water Pathways
	Initial (Gy)	Ongoing (at 0 a) (Gy·a^{-1})	Ongoing (at 0 a) (Gy·a^{-1})
Plant			
- actinides	10^{-2}	10^{-6}	10^{-2}
- Cs	10^{-3}	10^{-4}	10^{-2}
Mammal			
- actinides	10^{-6}	10^{-6}	10^{-4}
- Cs	10^{-3}	10^{-3}	10^{-2}
Bird			
- actinides	10^{-6}	10^{-6}	10^{-4}
- Cs	10^{-3}	10^{-3}	10^{-2}
Fish			
- actinides	-	-	10^{-1}
- Cs	-	-	1

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