PRELIMINARY DOSE ASSESSMENT OF ON-SITE BURIAL OF DECOMMISSIONING WASTE

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ABSTRACT

This paper presents an evaluation of the potential radiation dose from one of the alternatives being considered for the management of decommissioning wastes, namely the on-site burial of four reactor units in underground pits beneath the reactors at the Bruce Nuclear Generating Station A. The reactor and other contaminated components were assumed to leach activity into the groundwater which then discharged into Lake Huron and was subsequently used by a farmer who was self-sufficient in all his food requirements. The maximum individual dose rate was conservatively calculated to be about 3 mrem/yr. Consequently, the on-site burial of reactor components is a viable management option for decommissioning wastes.

INTRODUCTION

Decommissioning of a nuclear station usually assumes that the station is dismantled and the radioactive material is removed from the site. The process involves cutting large contaminated components into smaller pieces suitable for shipping to some distant disposal facility.

An alternative disposal concept based on one-piece, on-site burial of CANDU reactors has been recently introduced (1). The concept has been developed using the Bruce Nuclear Generating Station A as a model. The station is located about 250 km northwest of Toronto on the shore of Lake Huron. The decommissioning of four 750 MWe reactor units assumes that the heavy water and irradiated fuel have been removed and that the primary heat transport system has been decontaminated. The station is assumed to be kept in a storage-with-surveillance mode for 30 years, allowing much of the short-lived radionuclides to decay to innocuous levels. After this cooling period, the reactor assemblies would be completely encapsulated in their biological shield tanks and buried in the bedrock under their present locations. The four burial pits each have dimensions 14 m x 18 m x 55 m deep and the top of the vault is located about 20 m below the site surface. The pits will be backfilled with excavated rock and concrete to minimize voids. The on-site burial concept is illustrated in Figure 1.

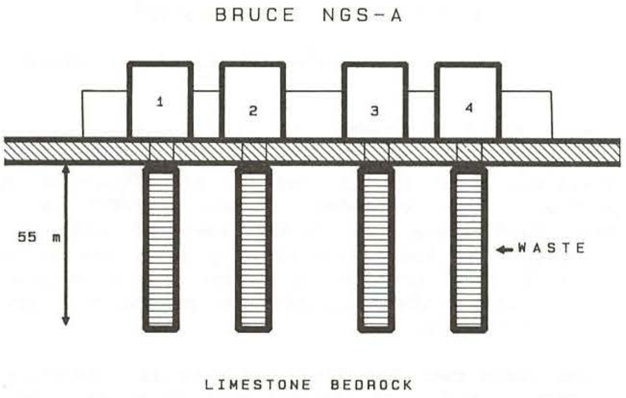

FIGURE 1: ARRANGEMENT OF BURIAL PITS FOR ON-SITE BURIAL OF DECOMMISSIONING WASTE AT BRUCE NGS A

SOURCE TERM

The radionuclide inventory in the burial pits will consist of fission and corrosion products and activated reactor components. Most of the fission and corrosion products will be removed during decontamination; however, some residual contamination will remain. No credit has been taken for the structural integrity of the components in the burial pit. Groundwater was assumed to contact the reactor components immediately after emplacement in the vault.

The sources of residual activity are activated corrosion products and fission products. These contaminants are incorporated into the oxide layers on the insides of the piping and components which transport the primary heat transport and moderator fluids. Chemical decontamination of these systems will remove most of the radioactivity.

After a 30-year cooling period, the remaining residual activity was conservatively assumed to be readily leached after emplacement in the burial pit and contact with groundwater. The residual activity inventory per reactor unit is listed in Table 1. The total activity was calculated to be less than 3.7×10^{10} Bq (1 Ci) using a decontamination factor of 50 and a 30-year cooling period. The residual activity was conservatively assumed to be leached into the groundwater within one year.

TABLE 1: RESIDUAL ACTIVITY PER UNIT AT BNGS A

Radionuclide	Inventory* (Bq)
Co-60	1.4×10^9
Cs-137	4.4×10^9
Pu-238	1.1×10^9
Pu-239	5.3×10^9
Pu-240	5.3×10^9
Am-241	1.9×10^9

* Inventory after 30-year decay period.

The fixed activity in the carbon steel, austenitic stainless steel (SS304L), martensitic stainless steel (SS403) and the zirconium/niobium pressure and calandria tubes (PT/CT) were determined using the ORIGEN computer code (2). Activation of these reactor components was based on a 40 year irradiation period and a 30 year cooling time. The activities per reactor unit are given in Table 2.

The leach rate for fixed activity is a function of the corrosion of the material in groundwater. The corrosion rate for carbon steel in groundwater at Bruce has been calculated to be 35×10^{-6} m/yr. The corrosion rate for stainless steel SS403 and SS304L was assumed to be 0.3×10^{-6} m/yr (3). Although the corrosion rate of the pressure and calandria tubes (Zr/Nb) is expected to be several orders of magnitude less than stainless steel, a value of 0.03×10^{-6} m/yr was conservatively assumed.

The fractional leach rate was calculated using the components density, surface area and corrosion rate. The radionuclide concentration at the burial pit can be written as:

$$C(t) = \frac{Lr\ Ao}{Q} \exp\,(-\ \lambda\ -\ Lr)t \qquad (1)$$

$$= Co \exp\,(-\ \alpha t)$$

where Lr is the fractional leach rate (yr^{-1}), Ao is the initial radionuclide inventory (Bq), Q is the groundwater flow through the burial pit (m^3/yr) and λ is the radionuclide decay constant (yr^{-1}). The decay parameter α was averaged over the four reactor components to approximate the leaching mechanism.

GEOSPHERE TRANSPORT

The mathematical description for radionuclide transport in the sub-surface environment at Bruce NGS A can be written as a one-dimensional dispersion-advection equation (4):

$$D \frac{d^2C}{dx^2} - \nu \frac{dC}{dx} - \lambda RC = R \frac{dC}{dt} \qquad (2)$$

where C is the radionuclide concentration in groundwater, D is the dispersion coefficient, ν is the groundwater velocity in the x-direction and R is the chemical retardation factor for the particular radionuclide. The retardation factor R is given by:

$$R = 1 + \frac{\rho\ Kd}{\theta} \qquad (3)$$

where ρ is the soil bulk density (g/ml), Kd is the distribution coefficient of the radionuclide (ml/g) and θ is the soil porosity. The Kd values were conservatively assumed to be 10 ml/g for all radionuclides except carbon-14, which had

TABLE 2: FIXED ACTIVITY PER UNIT AT BNGS A

	Inventory* (Bq)			
Radionuclide	Carbon Steel	SS403	SS304L	PT/CT
C-14	3.1×10^{12}	0	1.4×10^{14}	0
Fe-55	5.2×10^{12}	3.3×10^{12}	1.5×10^{14}	1.9×10^{12}
Co-60	2.6×10^{12}	4.8×10^{12}	1.1×10^{15}	2.4×10^{13}
Ni-59	7.4×10^{10}	2.6×10^{11}	3.7×10^{14}	1.4×10^{12}
Ni-63	8.1×10^{12}	2.6×10^{13}	3.7×10^{16}	1.1×10^{14}
Zr-93	0	0	0	1.1×10^{13}
Nb-94	0	0	0	1.0×10^{13}
Mo-93	0	0	0	1.0×10^{11}
Sn-121m	0	0	0	1.0×10^{11}

* Inventory after 40-year service life and 30-year cooling time.

a Kd of 0 ml/g. The average groundwater velocity in the Bruce geomedia was conservatively assumed to be 3 m/yr and the distance from the burial pit to Lake Huron was 300 m (see Figure 2). Therefore, the groundwater travel time from the burial pit to the lake was about 100 years.

The source term for each reactor unit was modelled by assuming a source 18 m wide and 55 m deep. The source was oriented perpendicular to the groundwater flow which was the x-direction. The radionuclide flux at the disposal pits (x=0) was assumed to be:

$$(- D \frac{dC}{dx} + \nu C) = \nu Co \exp(-\alpha t) \qquad (4)$$

The analytical solution to the above model was developed by Javandel, Doughty and Tsang (4) and can be easily evaluated to give the groundwater concentration at the discharge location as a function of time after burial.

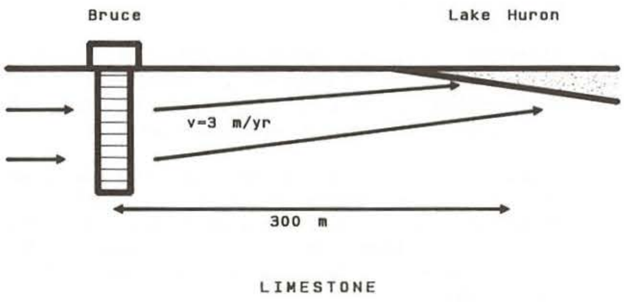

FIGURE 2: ENVIRONMENTAL MODEL FOR DECOMMISSIONING WASTES

BIOSPHERE TRANSPORT

The groundwater radioactivity was assumed to discharge into Lake Huron. Modelling the dispersion and transport of radioactivity entering a lake the size of Lake Huron is complicated by the dynamic nature of water along the shoreline. The lake currents near Bruce NGS A usually run parallel to the shoreline and the direction of flow changes on average every few days, mixing with the deeper lake waters. The dilution of radioactivity in Lake Huron was modelled by treating the shoreline currents as a river. The net shoreline current was assumed to be 160 m/hr and the width of this "river" was conservatively assumed to be 100 m, with a constant depth of 2 m. Therefore, the lake dilution flow rate was assumed to be 7.8×10^5 m^3/day. (As a comparison, the condenser cooling water flow at Bruce NGS A is about an order of magnitude greater at 7×10^6 m^3/day.)

The radiological pathways to man were based on the lake water exposure scenario. Near the discharge area, the contaminated lake water was conservatively assumed to be used by a farmer who is self-sufficient in all food requirements. The water was assumed to be used for drinking, irrigating vegetable crops, watering of livestock and general domestic use. The farmer was also assumed to consume fish from the contaminated lake water. The exposure pathway methodology, transfer parameters and dose conversion factors were taken from Gorman (5) and the doses were calculated using the PATHWAY-II environmental assessment code (6). The maximum dose rate and the time of the peak dose after burial are listed in Table 3. The time-dependent nature of the dose rate is illustrated in Figure 3.

TABLE 3: DOSE RESULTS

Radionuclide	Dose Rate* (Sv/yr)	Time** (yr)
C-14	3×10^{-5}	120
Fe-55	$< 10^{-9}$	-
Co-60	$< 10^{-9}$	-
Ni-59	4×10^{-8}	4700
Ni-63	$< 10^{-9}$	-
Zr-93	2×10^{-7}	4700
Nb-94	2×10^{-8}	4700
Mo-93	$< 10^{-9}$	-
Sn-121m	$< 10^{-9}$	-
Cs-137	$< 10^{-9}$	-
Pu-238	$< 10^{-9}$	-
Pu-239	5×10^{-7}	4000
Pu-240	6×10^{-7}	4000
Am-241	$< 10^{-9}$	-

* Maximum annual dose rate; includes all four units at BNGS A.

** Time of maximum annual dose rate after burial.

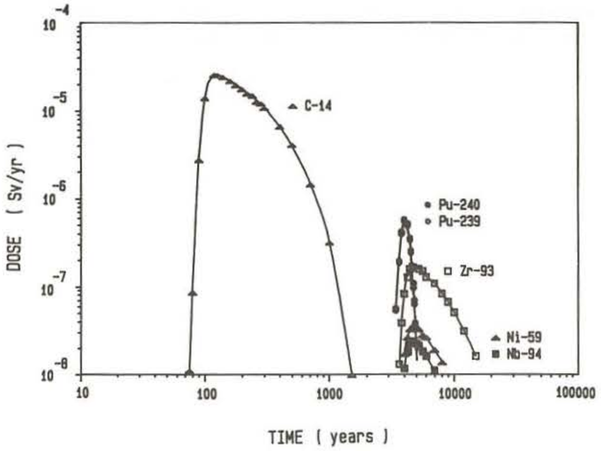

FIGURE 3: PUBLIC DOSE FROM DECOMMISSIONING WASTE

DISCUSSION

The predicted maximum annual dose rate of 3×10^{-5} Sv/yr was significantly below the Atomic Energy Control Board public dose limit of 5×10^{-3} Sv/yr. The critical radionuclide was C-14 and the critical pathway was fish ingestion. Since C-14 was assumed to have a Kd of 0 ml/g, its transit time through the geosphere was about 100 years. With a radioactive half-life of 5,730 years, most of the C-14 that entered the geosphere was calculated to exit into the biosphere.

The shorter-lived radionuclides, such as Fe-55, Co-60 and Cs-137, were not significant contributors to the individual dose estimates. This was due primarily to the long transit time of about 4,000 years through the geosphere for radionuclides with a Kd of 10 ml/g. Only the longer-lived radionuclides (Ni-59, Zr-93, Nb-94, Pu-239, Pu-240) and C-14 affected the dose outcome.

Figure 3 illustrates the individual dose rate versus time after closure of the burial pit. In the early stages, the doses are dominated by carbon-14 exposures. This was due to a large inventory of carbon-14 in carbon steel (Table 2) coupled with a relatively large leach rate, as compared with the other reactor components, and short transit time through the geosphere.

At times approaching 4,000 to 5,000 years after closure, the long-lived but chemically retarded radionuclides made a smaller contribution to the dose rate than did carbon-14. Consequently, carbon-14 was the radionuclide of concern in this assessment of on-site burial of decommissioning waste.

CONCLUSION

The individual dose resulting from the on-site burial of decommissioning waste from the Bruce Nuclear Generating Station A has been conservatively estimated to be 3×10^{-5} Sv/yr or 3 mrem/yr. This dose rate was due primarily to carbon-14 leached from the carbon steel and stainless steel reactor components. The actual dose rate is expected to be less than the value quoted here because of the large degree of conservatism employed in the analysis. From a radiological safety perspective, the on-site burial of the Bruce reactors is a viable management option for decommissioning.

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