PRELIMINARY ASSESSMENT OF ONTARIO HYDRO'S LOW LEVEL WASTE DISPOSAL CONCEPTS

Sean B. Russell and Brian J. Green
Ontario Hydro
700 University Avenue
Toronto, Ontario Canada
M5G 1X6

ABSTRACT

A program is underway at Ontario Hydro to evaluate the radiation safety of several radioactive waste disposal concepts in generic geologic environments. The goal of radioactive waste disposal is to isolate the wastes until they radioactively decay to innocuous levels, and at such time, pose little risk to the public. The three disposal concepts assessed in this study include near surface disposal in engineered trenches in glacial till, intermediate depth disposal in limestone caverns and deep disposal in shale and limestone. For each disposal concept, the critical individual was assumed to be exposed to contaminated well water and/or contaminated river water. Key parameters that affect an individual's dose rate are discussed and the dose results are compared among the disposal concepts. The maximum individual dose rate was found to be of the order of 1 mrem/yr.

INTRODUCTION

Ontario Hydro is the publicly-owned electrical utility in the Province of Ontario and has 15 nuclear reactor units in-service and 6 units under construction. Low level radioactive wastes (LLW) are currently stored at the Radioactive Waste Operations Site located at the Bruce Nuclear Power Development. These wastes include contaminated housekeeping materials such as paper and plastic sheeting, used rubber gloves and plastic suits, mops, rags and non-processible wastes such as piping, valves and other components. Ion exchange resins and filters contain higher levels of radioactivity and are not included in the LLW category. Processible wastes are volume reduced by incineration or compaction and stored in concrete trenches and a low level waste storage building.

Disposal is one option in Ontario Hydro's systems approach to radioactive materials management[1,2]. It is being investigated to provide safe management of wastes which will remain hazardous beyond the operating lifetime of the storage facilities.

The radiation criteria for ranking potential reactor waste disposal concepts were previously presented[3]. The present paper describes the preliminary dose estimates to an individual for two exposure scenarios and three geologic disposal concepts. Economic and social criteria are not considered in this paper.

DISPOSAL CONCEPTS

Methods for disposing of reactor wastes include near surface, intermediate depth and deep disposal on land, burial in lake or ocean sediments and lake or ocean dumping. While each of these options is technically feasible, land-based disposal concepts were selected for investigation because of economic and socio-political considerations.

Engineered Trenches

Engineered trenches are assumed to be constructed by near-surface excavation of glacial till to a depth of about 10 m (Fig. 1). Concrete structures are constructed along the bottom and sides of the trench. The waste containers are placed in layers in the bottom of the trench and the trench is backfilled with concrete to fill the voids. Once a trench is filled, a concrete cover is cast on the top and a multi-layered cover of soil, gravel and clay is placed over the trench to control surface water infiltration and erosion.

Another 10 m of till is assumed between the bottom of the trenches and the fractured bedrock. The hydraulic conductivity of the glacial till was assumed to be $5x10^{-8}$ cm/s, with an effective porosity of 0.2 and a vertically downward gradient of 0.75. Therefore, the groundwater velocity was assumed to be about 6 cm/yr. The water table in Ontario is generally within a few meters of the surface, therefore, the wastes were considered to be buried within the saturated zone.

Hydraulic conductivity along the bedrock surface was assumed to be $1x10^{-3}$ cm/s, with a porosity of 0.4 and a horizontal gradient of 0.04. This gives a groundwater velocity of about 30 m/yr. The thickness of the bedrock aquifer was assumed to be 3 m. Therefore, the timescale for radionuclide migration from the disposal trench to the biosphere will be controlled by the vertical transport within the glacial till unit.

Rock Caverns

An access tunnel is assumed to be excavated through the overburden and down to a depth of 50 m within a thick limestone unit as shown in Fig. 1. The drummed wastes are transported down the access ramp to disposal caverns which branch away from the main tunnel. The LLW containers are placed one layer at a time in the caverns and backfilled with concrete to eliminate voids and provide structural support. When full, a disposal cavern is assumed to

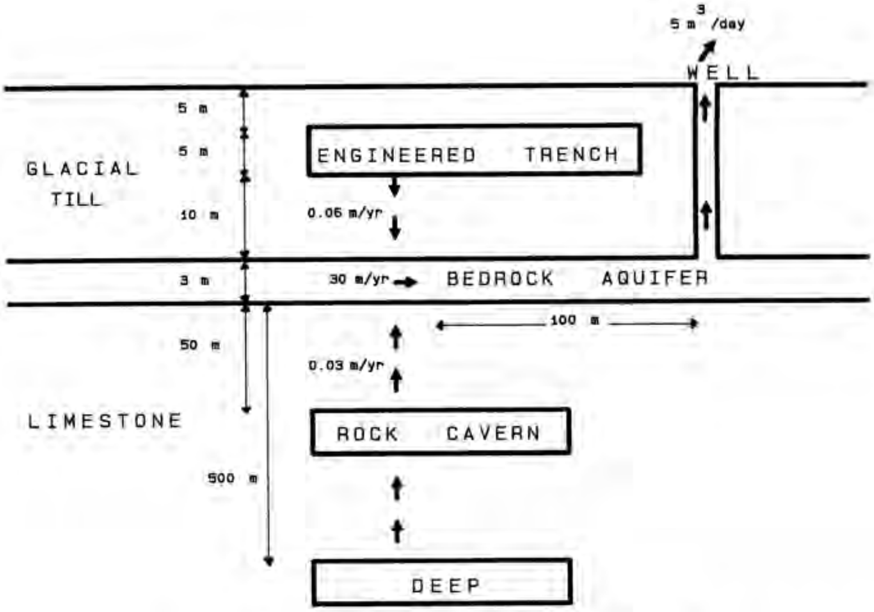

Fig. 1. Low level waste disposal concepts

be sealed from the access tunnel with a concrete closure plug. New disposal caverns are excavated, packed with waste and sealed, as required.

The distance between the waste caverns and the bedrock aquifer was assumed to be 50 m. The hydraulic conductivity of the limestone was 1×10^{-8} cm/s, with an effective porosity of 0.001 and a vertical hydraulic gradient of 0.01 upward. Thus, the groundwater velocity through the limestone was assumed to be upward at 3 cm/yr towards the fractured bedrock aquifer. The properties of the aquifer were assumed to be the same as in the trench disposal concept.

Deep Disposal

Deep geologic disposal of reactor wastes in limestone or similar geomedia at a depth of 500 m was investigated using the same hydrogeologic properties as in the intermediate depth disposal concept (Fig. 1). The 500 m depth would necessitate a vertical shaft access to the disposal vaults for waste emplacement. The drummed wastes are assumed to be backfilled with concrete and the cavern sealed after filling. It was assumed that the access shaft was backfilled with a suitable rock/clay combination such that the backfill material had a hydraulic conductivity similar to the host rock ($\sim10^{-8}$ cm/s).

Radionuclides leached from the disposal vault were assumed to migrate upward to a fractured bedrock aquifer as in the rock cavern disposal concept. The isolating effects of any overlying shale sequences were not credited in the analysis for conservatism. The relatively impermeable shale (hydraulic conductivity $\sim10^{-10}$ cm/s) would provide additional isolation of the waste, if taken into account.

The relevant hydrogeologic parameters for each disposal concept are summarized in Table I. The geosphere has been sub-divided into a vertical

TABLE I

Hydrogeologic Parameters

	Trench	Cavern	Deep
Vertical Zone			
Transport Distance (m)	10	50	500
Hydraulic Conductivity (m/s)	5×10^{-10}	1×10^{-10}	1×10^{-10}
Hydraulic Gradient	0.75	0.01	0.01
Effective Porosity	0.20	0.001	0.001
Longitudinal Dispersivity (m)	0.10	1.0	1.0
Transverse Dispersivity (m)	0.01	0.1	0.1
Horizontal Zone			
Transport Distance (m)	100	100	100
Hydraulic Conductivity (m/s)	1×10^{-5}	1×10^{-5}	1×10^{-5}
Hydraulic Gradient	0.04	0.04	0.04
Effective Porosity	0.4	0.4	0.4
Longitudinal Dispersivity (m)	1.0	1.0	1.0
Transverse Dispersivity (m)	0.1	0.1	0.1

transport zone through the primary isolation rock/soil sequence and a horizontal transport zone through the fractured bedrock aquifer. Groundwater from the aquifer may then enter the biosphere via a well or through groundwater discharge into a river or lake.

ASSESSMENT METHODOLOGY

Estimations of individual dose rates from exposure to radionuclides leached from a disposal vault into the surrounding geosphere are normally done using predictive models. Radionuclide transport in groundwater through the sub-surface environment is a complex phenomenon and is difficult to accurately predict. Many of the transport parameters such as chemical retardation of radionuclides and flow through inhomogeneous and fractured rock are poorly understood at this time. Consequently, simplified models are often used to simulate the transport of activity from a disposal facility.

For generic disposal assessments, analytical solutions to the contaminant transport problem are the most appropriate. (Once a site has been selected, then numerical models may be better suited if the geology is complex). The computer code SST[4] used in the analysis can simulate vertical and horizontal transport of radionuclides through soil that is porous, homogeneous and isotropic. Vertical transport is assumed to be caused by either water seepage through the unsaturated zone, or a vertical hydraulic gradient in the saturated zone. Horizontal transport is assumed to be caused by a horizontal hydraulic gradient in the aquifer. The SST code also allows for parametric and sensitivity analysis of several hydrogeologic variables.

The source term was based on projections of the total cumulative arisings of LLW at Ontario Hydro until the year 2000 and of the radioactivity in these wastes[3]. The radionuclides listed in Table II include only those nuclides with half-lives greater than two years. The other nuclides are assumed to decay to innocuous levels within the time frame of the disposal facility's operational phase. The wastes were assumed to be packaged in 210 liter drums with a total volume of 50,000 m^3.

TABLE II

Source Term

Radionuclide	Activity (Ci)
H-3	5.0×10^4
C-14	5.0×10^{-2}
Co-60	5.5×10^2
Sr-90	4.5×10^0
Cs-137	4.5×10^2

The radionuclides were assumed to be leached into the groundwater at the constant rate of 1% (of the initial inventory) per year until depleted. No credit was taken from sorption of radionuclides in the buffer or backfill material in the disposal vault. Tritium and carbon-14 were assumed to migrate unretarded in the groundwater and the distribution coefficients for cobalt-60, strontium-90 and cesium-137 were conservatively assumed to be 10 ml/g outside the vault.

EXPOSURE SCENARIOS

The critical pathway for radionuclide migration from a waste disposal vault to man is usually found to be via consumption of water drawn from a well connected to a contaminated aquifer. To allow for instances where this may not be a realistic or probable exposure scenario, discharge into a surface water body was also investigated.

Well Water

The well was assumed to be located 100 m along the aquifer from the waste source. Contaminated water was assumed to be pumped at the rate of 5 m^3/day (1300 gal/day) from a well that penetrated 3 m into the bedrock aquifer. This water was used for drinking, irrigation of vegetable crops, watering of livestock and bathing. The critical group was conservatively assumed to be a farmer who was self-sufficient in food and derived all his water requirements from the well.

River

In the river exposure scenario, groundwater from the aquifer was assumed to discharge into a river. The horizontal travel distance was assumed to be 100 m. The average flow rate of the river was taken as 1×10^5 m^3/day. The exposed individual was assumed to be the self-sufficient farmer considered in the well water exposure scenario. However, in addition to deriving all of his water requirements from the river, the consumption of fish from the river was also included in this dose assessment.

DOSE RATES

The maximum individual dose rates for the disposal concepts and exposure scenarios investigated are listed in Table III. The critical radionuclides were tritium and carbon-14 for well water exposure in the engineered trench concept and carbon-14 for the other exposure scenarios and disposal concepts. The individual dose rates are shown as a function of time after disposal in Fig. 2 for the well exposure scenario. The peak dose rates occurred at about 160, 1700 and 16000 years after disposal for the engineered trench, rock cavern and deep disposal concepts, respectively.

TABLE III

Maximum Dose Rate

Disposal Concept	Dose Rate (mrem/yr) Well	 River
Engineered Trench	1.8	$< 10^{-3}$
Rock Cavern	0.17	$< 10^{-3}$
Deep	0.037	$< 10^{-3}$

For well water exposures, the critical pathway was via drinking water. In the river exposure scenario, the critical pathway was via fish consumption.

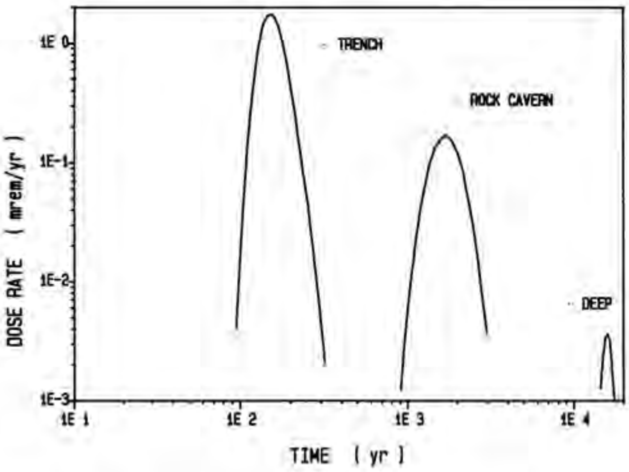

Fig. 2. Individual dose rate as a function of time after disposal for the well scenario.

Parameter Sensitivity

A parametric analysis was performed on several parameters in the geosphere portion of the SST code for the trench disposal concept and well exposure scenario. The key parameters were the groundwater velocity in the vertical transport zone, the distance to the bedrock aquifer, and the distribution coefficients for the radionuclides. The maximum individual dose rates are shown as a function of vertical groundwater velocity in Fig. 3 for tritium and carbon-14. The effects of varying the distribution coefficient (Kd) for the nuclides are shown in Fig. 4.

For the river exposure scenario, the key parameters were the same as those of the well scenario plus the flow rate of the river.

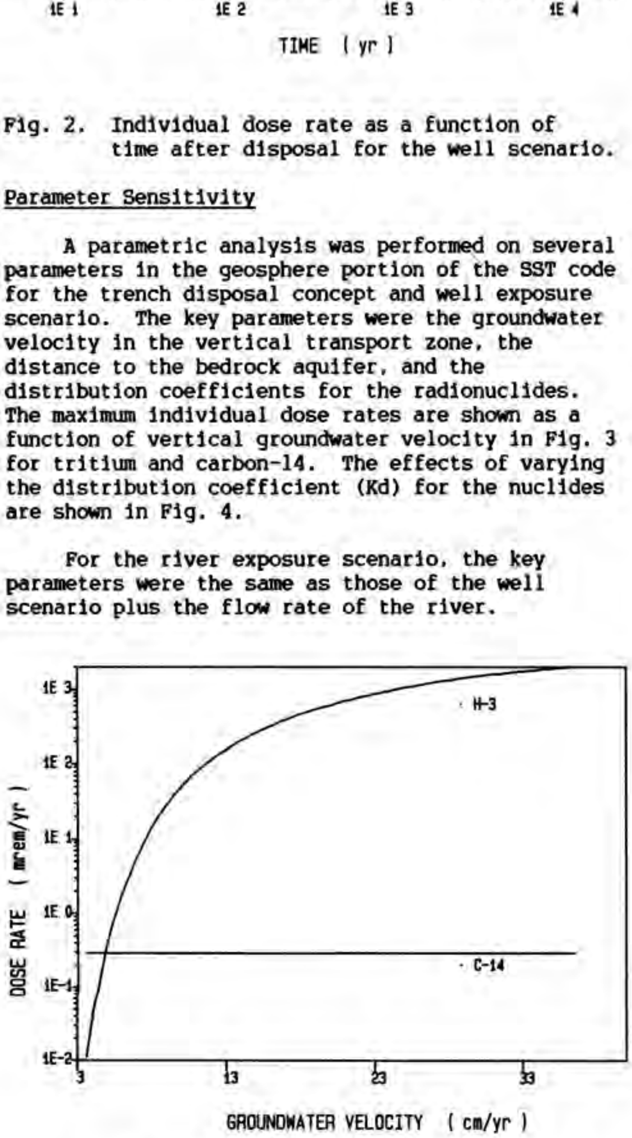

Fig. 3. Maximum dose rate versus vertical groundwater velocity.

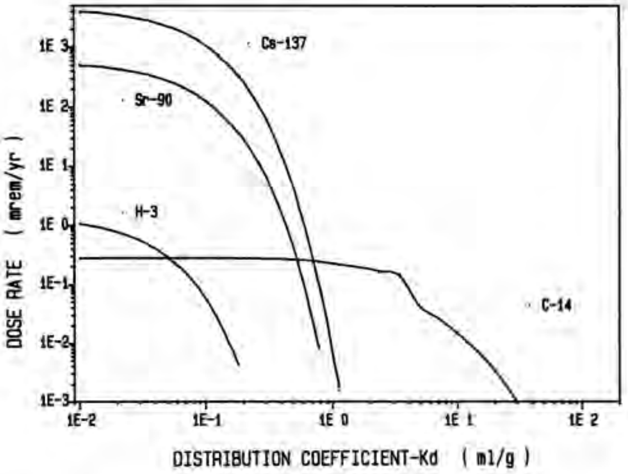

Fig. 4. Effects of distribution coefficient (Kd) on dose rate.

DISCUSSION

This generic radiation safety assessment has indicated that doses from the LLW disposal concepts being investigated at Ontario Hydro are of the order of 1 mrem/yr or less. These dose rates are significantly below the Atomic Energy Control Board dose limit of 500 mrem/yr for members of the public[5]. Doses from the river scenario were even smaller for each disposal concept. This was due primarily to the large dilution effect from the flowing river.

As illustrated in Fig. 2, the rock cavern and deep disposal options resulted in lower dose rates than the near-surface engineered trench option. Greater isolation times and dispersion in the geosphere were the principal reasons for the reduction of dose with the deeper disposal options. The dose rate for times greater than several hundred years after disposal was due entirely to carbon-14 exposures.

Disposal of LLW at intermediate depth in rock caverns or at greater depth in limestone resulted in dose rates of about 0.1 mrem/yr or less. No credit was taken for any absorption of carbon-14 in the buffer or backfill material in the disposal vault. Consequently, the dose estimates are conservative and indicate that disposal of LLW in deep rock formations is probably not necessary for radiation protection purposes. Disposal at intermediate depth does provide greater isolation and less probability for intrusion than the engineered trench concept.

The most sensitive parameter in the trench concept was the groundwater velocity in the vertical transport zone. As illustrated in Fig. 3, a change in groundwater velocity from 3.7 cm/yr to 37 cm/yr produced a five order of magnitude increase in dose rate from tritium, while the dose from carbon-14 remained constant. At the lower velocity a significant fraction of the tritium decayed in the geosphere before reaching the well. However, at the larger groundwater velocity, and therefore, shorter travel time, tritium would reach the well at a higher concentration. The effect of this parameter on carbon-14 was insignificant due to the long radiological half-life of carbon-14.

The vertical distance to the aquifer had an effect on the dose rate similar to the groundwater velocity. This was due to the increase in transit time from the vault to the well as the travel distance increased.

Varying the distribution coefficient or Kd of the nuclides had a substantial effect on the dose rate from tritium, strontium-90 and cesium-137. The effect on the dose from carbon-14 was negligible until Kd was greater than 10 ml/g, and the dose from cobalt-60 was negligible throughout the Kd range due to its short half-life. While the doses from strontium-90 and cesium-137 are large for Kd near 0 ml/g, the Kd values reported in the literature[6] are generally much greater than 1 ml/g. The dose results indicate that only carbon-14 needs to be considered if the Kd for the nuclides is greater than 1 ml/g (Fig. 4).

CONCLUSIONS

The individual dose rates from the disposal of LLW in engineered trenches, intermediate depth rock caverns and deep disposal in limestone have been calculated using generic hydrogeologic parameters and conservative exposure scenarios. The maximum dose rates were found to be of the order of 1 mrem/yr or less for the well exposure scenario. Doses from the river exposure scenario were less than 10^{-3} mrem/yr due to the greater dilution effects of the river. Therefore, within the exposure scenarios and parameters examined in this assessment, the disposal concepts are acceptable for LLW disposal.

Tritium and carbon-14 were the critical radionuclides for the engineered trench concept and well exposure scenario. Carbon-14 was the critical radionuclide for all other disposal concepts and exposure scenarios investigated. The critical pathway to man was via drinking water for well exposure and via fish ingestion for river exposure.

The key hydrogeologic parameters in the radiation safety assessment were found to be the vertical groundwater velocity, the distance to the aquifer and the distribution coefficients for the nuclides. Doses from tritium were found to be very sensitive to the vertical groundwater velocity, whereas doses from carbon-14 were relatively insensitive to this parameter.

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