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PRELIMINARY POST-CLOSURE SAFETY ASSESSMENT OF REPOSITORY CONCEPTS FOR LOW LEVEL RADIOACTIVE WASTE AT THE BRUCE SITE, ONTARIO

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ABSTRACT

The preliminary post-closure safety assessment of permanent repository concepts for low-level radioactive waste (LLW) at the Ontario Power Generation (OPG) Bruce Site is described. The study considered the disposal of LLW. Four geotechnically feasible repository concepts were considered (two near-surface and two deep repositories). An approach consistent with best international practice was used to provide a reasoned and comprehensive analysis of post-closure impacts of the repository concepts. The results demonstrated that the deep repository concepts in shale and in limestone, and the surface repository concept on sand should meet radiological protection criteria. For the surface repository concept on glacial till, it appears that increased engineering such as grouting of waste and voids should be considered to meet the relevant dose constraint. Should the project to develop a permanent repository for LLW proceed, this preliminary safety assessment would need to be updated to take account of future site-specific investigations and design updates, and to include consideration of intermediate-level radioactive waste (ILW).

1. INTRODUCTION

In April 2002, the Municipality of Kincardine and Ontario Power Generation Inc. (OPG) agreed to explore options for the long-term management of low-level radioactive waste (LLW) and intermediate-level radioactive waste (ILW) at the Bruce Site in Ontario. The plan included a review of permanent repository concepts and as part of this review, two studies were commissioned. The first identified four geotechnically feasible repository concepts [1]. The second study was a preliminary assessment of the long-term radiological safety of these repository concepts [2]. This second study is summarised in this paper.

The safety assessment used an approach that was consistent with best international practice as developed under a research programme (Improvement of Safety Assessment Methodologies for Near Surface Disposal Facilities (ISAM)) of the International Atomic Energy Agency [3]. The approach is designed to provide a reasoned and comprehensive analysis of post-closure radiological impacts of the repository concepts. It consists of the following steps:

(1) specification of the assessment context (what is being assessed and why it is being assessed);
(2) description of the repository system (the near field, geosphere and biosphere);
(3) development and justification of the scenarios to be assessed;
(4) formulation and implementation of models and associated data; and
(5) presentation and analysis of the results.

2. SPECIFICATION OF THE ASSESSMENT CONTEXT

The assessment context reflected the preliminary nature of the work to investigate the suitability of permanent repository concepts at the Bruce Site. The specific purposes were:

(1) to assess the post-closure radiological safety of a waste repository at the Bruce Site;
(2) to help identify potentially acceptable repository concept(s) at the Bruce Site;
(3) to provide insight with respect to the level of engineering barrier systems required for the identified concept(s) to meet safety criteria; and
(4) to identify where further data or information would be most useful.

Only LLW was considered. For all events other than human intrusion, an annual individual effective dose rate constraint of 0.3 mSv y^{-1} was applied. For human intrusion, two threshold values were considered: 1 mSv y^{-1}, below which optimization of the repository system was not considered necessary; and 100 mSv y^{-1}, above which efforts must be made to reduce the consequences of human intrusion to below this level. These criteria are based on the recommendations given in Publication 81 of the International Commission on Radiological Protection (ICRP) [4] with the exception that the criteria for human intrusion are more restrictive than ICRP.

3. DESCRIPTION OF THE REPOSITORY SYSTEM

3.1. The Near Field

The focus of the study was the development of a repository with capacity for 89,000 m^3 of LLW arising from the operation of OPG's and Bruce Power's nuclear power plants. The reference LLW inventory has a total activity of 1.2×10^{13} Bq and will be packaged in 20,000 containers (drums and boxes) constructed of mild steel. Four geotechnically feasible repository concepts were identified for the emplacement of LLW [1]:

(1) Covered Above Grade Concrete Vault on sand (CAGCV-S);
(2) Covered Above Grade Concrete Vault on till (CAGCV-T);
(3) Deep Rock Cavern Vault in shale (DRCV-S) at a depth of 460 m; and
(4) Deep Rock Cavern Vault in limestone (DRCV-L) at a depth of 660 m.

The schematic of the CAGCV and DRCV concept is given in Figure 1 and Figure 2 respectively.

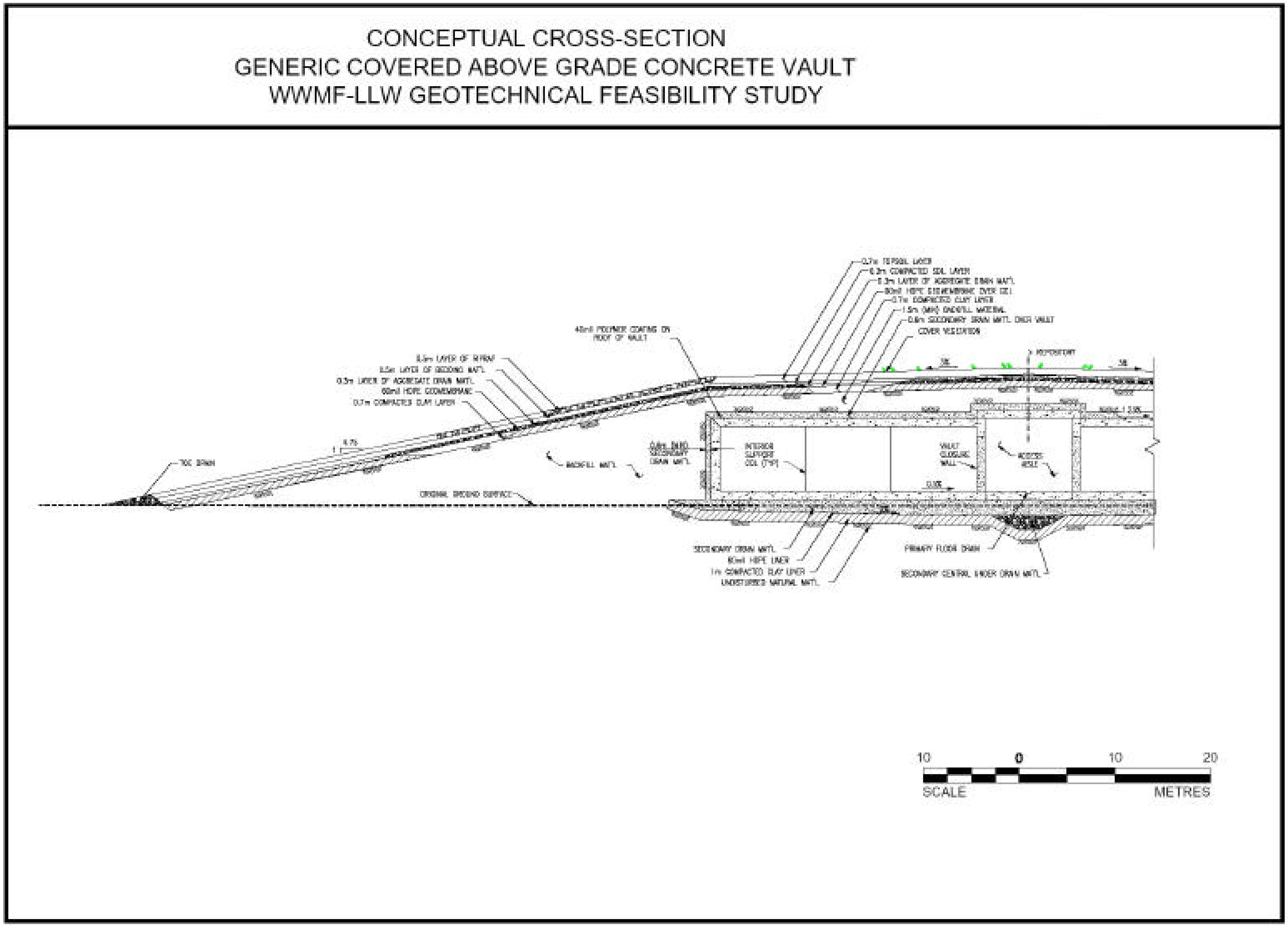

Figure 1: Conceptual Cross-section through the CAGCV [1]

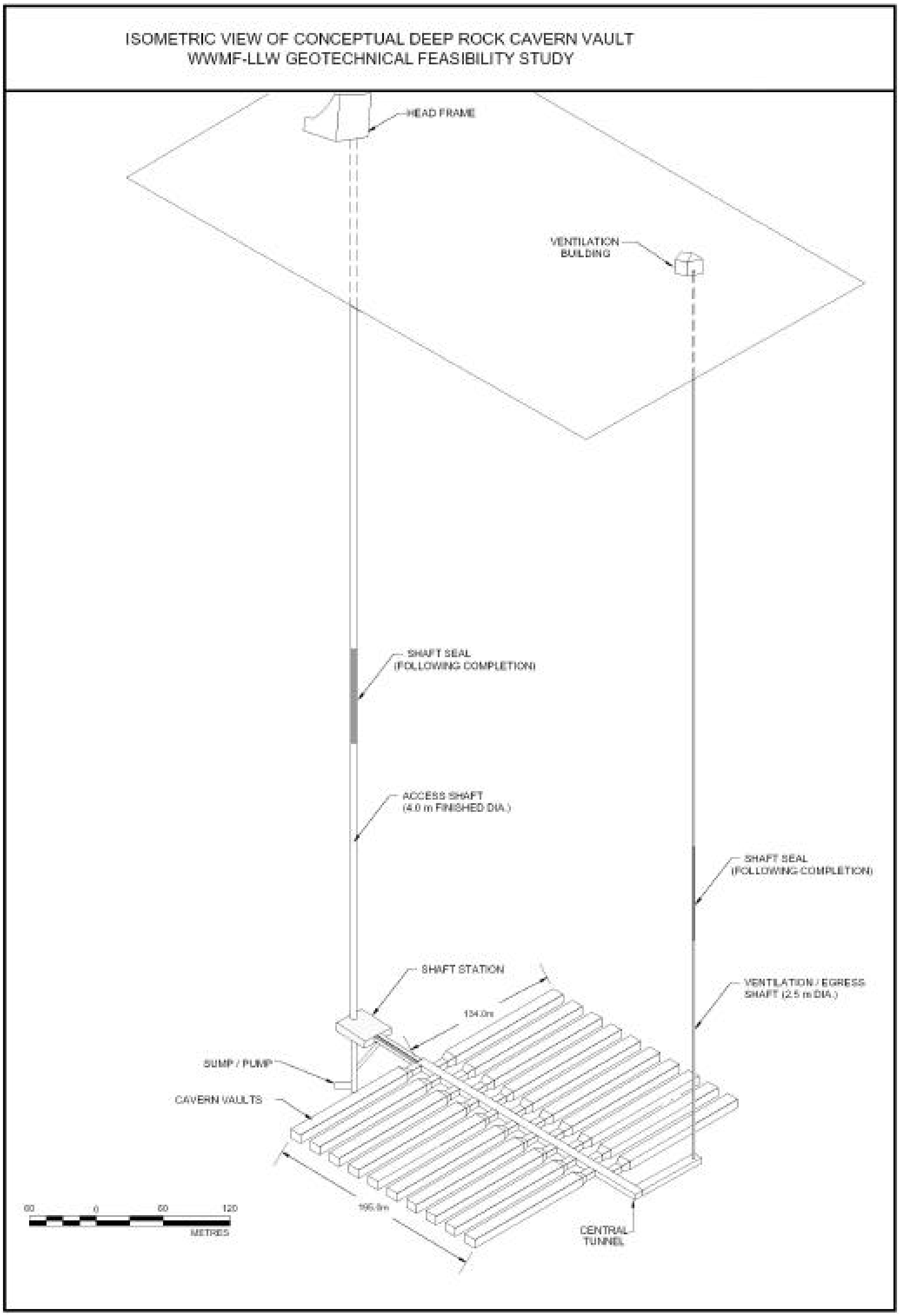

Figure 2: Conceptual Cross-section through the DRCV [1]

3.2. The Geosphere

The Bruce Site lies on the eastern edge of the Michigan Basin. The Palaeozoic bedrock sequence overlying Precambrian granitic basement comprises from the top down:

- approximately 375 m of Devonian and Silurian dolostones (dolomitic limestones);
- approximately 230 m of Lower Silurian – Upper Ordovician shale; and
- 185 - 190 m of Middle Ordovician fine grained, argillaceous to shaly limestone.

Unconsolidated ('overburden') sediments with a thickness of between 1 and 20 m overlie this bedrock sequence. These sediments are comprised of a comparatively complex sequence of surface sands and gravels from former beach deposits overlying glacial till with interbedded lenses and layers of sand of variable thickness and lateral extent.

Four groundwater systems have been identified (Figure 3):

(1) **The Surficial Deposits (Overburden) Groundwater System** – a series of local aquifers, which flow westward towards Lake Huron, and aquitards.

(2) **The Shallow Bedrock Groundwater System** – the upper portions contain fresh water, while at greater depths, sulphur rich water occurs. Groundwater flows westward into Lake Huron.

(3) **The Intermediate Bedrock Groundwater System** – the upper portion is typically freshwater or sulphur water, whilst the lower portion can contain either sulphur or saline water. Lake Huron is considered to be the ultimate receptor of groundwater within this system.

(4) **The Deep Bedrock Groundwater System** – is associated with the low permeability Ordovician shales and limestones. The groundwater is saline and the movement of pore water is very slow.

3.3. The Biosphere

The Bruce Site is located on the east shore of Lake Huron. The annual average precipitation is 0.86 m y^{-1} and the annual average temperature is 7 ºC. There are no major rivers in the vicinity of the Bruce Site, although there are several small streams that eventually drain into Lake Huron. The region around the Bruce Site is mainly used for agriculture, recreation and some residential development. Farmland accounts for around 60% of the land use in Bruce County, with many cattle farmers, as well as farmers of pigs and sheep, and crops such as oats, barley, canola and hay. Both municipal and domestic users of groundwater exist in the vicinity of the Bruce Site. Water is drawn from the Shallow Bedrock Groundwater System at depths of between 30 and 100 m.

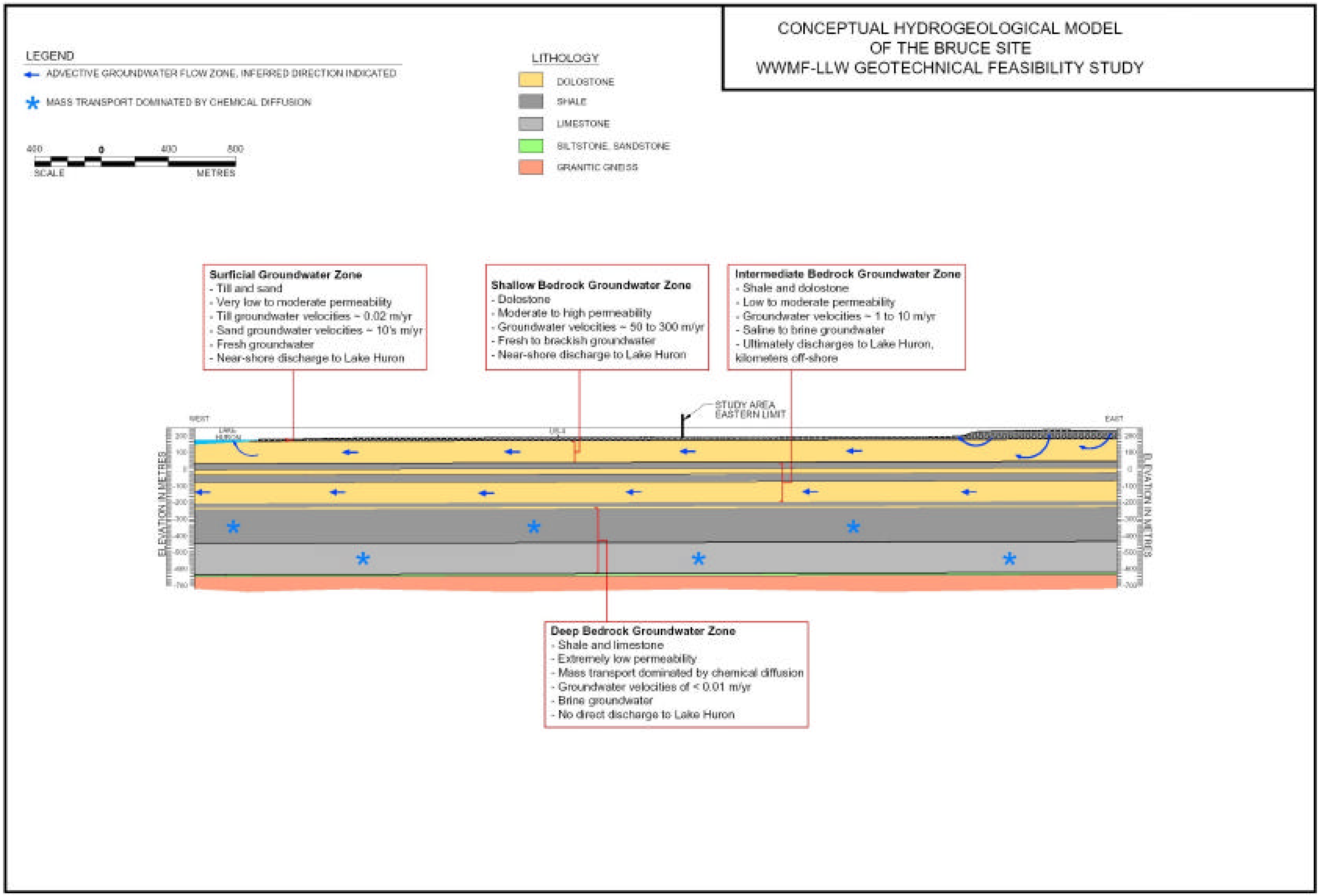

Figure 3: Conceptual Hydrogeology Model of the Bruce Site [1]

4. DEVELOPMENT AND JUSTIFICATION OF SCENARIOS

Based largely on expert judgement and use of the ISAM list of features, events and processes (FEPs), two scenarios were considered. The **Reference Scenario** considered the gradual release of radionuclides from the repository in liquid, gaseous and solid form due to natural processes such as leaching, gas generation and erosion. The subsequent migration and accumulation of radionuclides in the environment and the resulting potential exposure of humans to the radionuclides was considered. The **Human Intrusion Scenario** considered the possible inadvertent disruption of the wastes in the future. Two main categories of disruption were considered: small (drilling of boreholes during site investigation resulting in the potential direct exposure of individuals to essentially undiluted waste materials); and large (large scale excavations resulting in the potential exposure of both the intruder and individuals with no direct connection to the intrusion event, but who may nevertheless encounter waste materials incorporated into local surface environmental media).

5. FORMULATION AND IMPLEMENTATION OF MODELS AND DATA

A total of ten calculation cases were identified associated with these two scenarios (Table 1). Each had a specific conceptual model that provided a description of the release, migration and fate of radionuclides from the repository and the associated FEPs considered in the model. The FEPs associated with each conceptual model were represented using algebraic expressions within a mathematical model. Site-specific data were obtained and supplemented with other information, e.g., from published compilations of data. The mathematical models and associated data were then implemented in a software tool (AMBER) [5] to simulate the migration of radionuclides from the near field into the environment, and calculate the resulting dose consequences for each calculation case.

6. PRESENTATTION AND ANALYSIS OF RESULTS

Comprehensive results from all calculation cases for permanent waste repository concepts can be found in the detailed preliminary safety assessment report [2]. The key results for potentially acceptable repository concepts (DRCV-S, DRCV-L, CAGCV-S and CAGCV-T) are summarised in Table 2, Figure 4 and Figure 5. The main findings are as follows.

- For the deep repository concepts (DRCV-S and DRCV-L), the calculated dose rates are below the ICRP 81 dose criteria by many orders of magnitude for all of the calculation cases. Grouting the wastes and the repository voids reduces the calculated dose rates from liquid releases by less than an order of magnitude because the release is already significantly restricted by the low permeability host rocks at depth.

- For the surface repository concept on sand (CAGCV-S), the calculated dose rates are below the ICRP 81 dose criteria for all of the calculation cases by about an order of magnitude or more. Grouting the wastes and the repository voids limits the flow of water through the repository and increases the retention time of radionuclides in the near field, thus reducing the calculated dose rates from liquid releases by at least an order of magnitude. For the surface repository concept on glacial till (CAGCV-T), it appears that increased engineering such as grouting of waste and voids should be considered to meet the ICRP 81 dose criteria.

- Varying the institutional control period between 100 years and 300 years has no impact on the calculated peak dose rates for the Reference Scenario for all these cases. This is because the calculated peak dose rates arise thousands of years after the loss of institutional control. The calculated dose rates for the most significant calculation case in the period between 100 and 300 years (i.e., the Gas Release Calculation Case) are more than three orders of magnitude below the ICRP dose criterion of 0.3 mSv y^{-1}. For the Human Intrusion Scenario, calculated dose rates are higher in the period between 100 years and 300 years because there is less time for radioactive decay and leaching to reduce the inventory in the repository. Nevertheless, calculated dose rates for the most restrictive calculation case are still more than an order of magnitude below the level above which reasonable efforts should be made to reduce the likelihood of human intrusion or to limit its consequences.

7. CONCLUSIONS

A preliminary assessment was undertaken to assess the post-closure radiological safety of four geotechnically feasible repository concepts for the long-term management of LLW at the Bruce Site. The assessment used an approach consistent with best international practice.

The assessment results demonstrated that, from a post-closure radiological safety assessment perspective, the deep repository concepts in shale (DRCV-S) and limestone (DRCV-L), and the surface repository concept on sand (CAGCV-S) should meet the radiological protection criteria adopted for this study, even without grouting of the waste and repository voids. Whilst grouting has benefits for the surface repository concepts such as reducing and/or delaying dose rates, its benefits for the deep repository concepts are minimal. Although extending the institutional control period from 100 to 300 years has no significant impact on the dose rates for the limiting calculation cases for the Reference Scenario, it does reduce calculated dose rates for Human Intrusion Scenario calculation cases, but only by about a factor of three. Furthermore, the calculated dose rates at 100 years for the most restrictive calculation case are still more than an order of magnitude below the level above which reasonable efforts should be made to reduce the likelihood of human intrusion or to limit its consequences.

The ability of the repository designs to accept OPG's ILW was assessed qualitatively. Due to the very low permeability of the host rocks, the deep repository concepts in shale (DRCV-S) and limestone (DRCV-L) are likely to meet the radiological protection criteria adopted for this study for a wide range of ILW, although quantitative analyses would be required to confirm this. The surface repository concept on sand (CAGCV-S) would require additional analyses to ascertain the degree to which the concept could accept ILW.

Table 1: Calculation Cases for Assessment

Scenario	Release Mechanism	Calculation Case Name	Permanent Repository Concept(s)	Potential Exposure Group(s)	Features
Reference Scenario	Liquid	Lake Release	CAGCV-S, CAGCV-T	Fisherman	Contaminated groundwater released to overburden sediments and transported to lake via Shallow Bedrock Groundwater System.
		Lakeshore Release	CAGCV-S, CAGCV-T	Fisherman	Contaminated groundwater released to overburden sediments and transported to lakeshore via Shallow Bedrock Groundwater System.
		Well Release	CAGCV-S, CAGCV-T	Farmer	Contaminated groundwater released to overburden sediments and transported to well via Shallow Bedrock Groundwater System.
		Bathtubbing	CAGCV-T	Site dweller	Contaminated groundwater released directly into soil after degradation of near-field barriers.
	Gas	Gas Release	CAGCV-S, CAGCV-T	Site dweller	Contaminated gas released into a house on the cap after failure of containers or loss of institutional control (whichever is later).
	Solid	Cover Erosion	CAGCV-S, CAGCV-T	Site dweller	Waste exposed at the surface after degradation of near-field barriers and its erosion by wind and water.
	Liquid	Lake Release	DRCV-S, DRCV-L	Fisherman	Contaminated groundwater released by diffusion to Intermediate Bedrock Groundwater System, then transport to off-shore lake sediments.
	Liquid	Shaft Pathway	DRCV-S, DRCV-L	Fisherman	Contaminated groundwater released via shaft and transported via enhanced diffusion to Intermediate Bedrock Groundwater System, then transport to off-shore lake sediments.
Human Intrusion Scenario	Solid	Exploration Borehole	CAGCV-S, CAGCV-T, DRCV-S, DRCV-L	Intruder	Waste retrieved to the surface via shallow (CAGCV) or deep (DRCV) borehole.
		Excavation	CAGCV-S, CAGCV-T	Intruder, Site dweller	Large excavation disrupts waste and spoil from large excavation contaminates surface soils, which are then farmed.

Note: All calculation cases for the CAGCV and DRCV concepts were considered for both grouting and non-grouting options.

Table 2: Summary of Key Results for the Potentially Acceptable Repository Concepts

Scenario	Repository Concept	Time of Peak Dose (y)	Peak Dose Rate (mSv y^{-1})	Most Significant Calculation Case
Reference	DRCV-S	47,500	5×10^{-14}	Shaft Pathway
Reference	DRCV-L	65,000	2×10^{-14}	Shaft Pathway
Reference	CAGCV-S	7,500	0.007	Well Release
Human Intrusion	DRCV-S	300	3×10^{-5}	Borehole
Human Intrusion	DRCV-L	300	3×10^{-5}	Borehole
Human Intrusion	CAGCV-S	300	0.03	Excavation

Note: Non-grouting option. An institutional control period of 300 years was assumed for the purposes of this table. The effect of reducing this period to 100 years is minimal (see Figure 5).

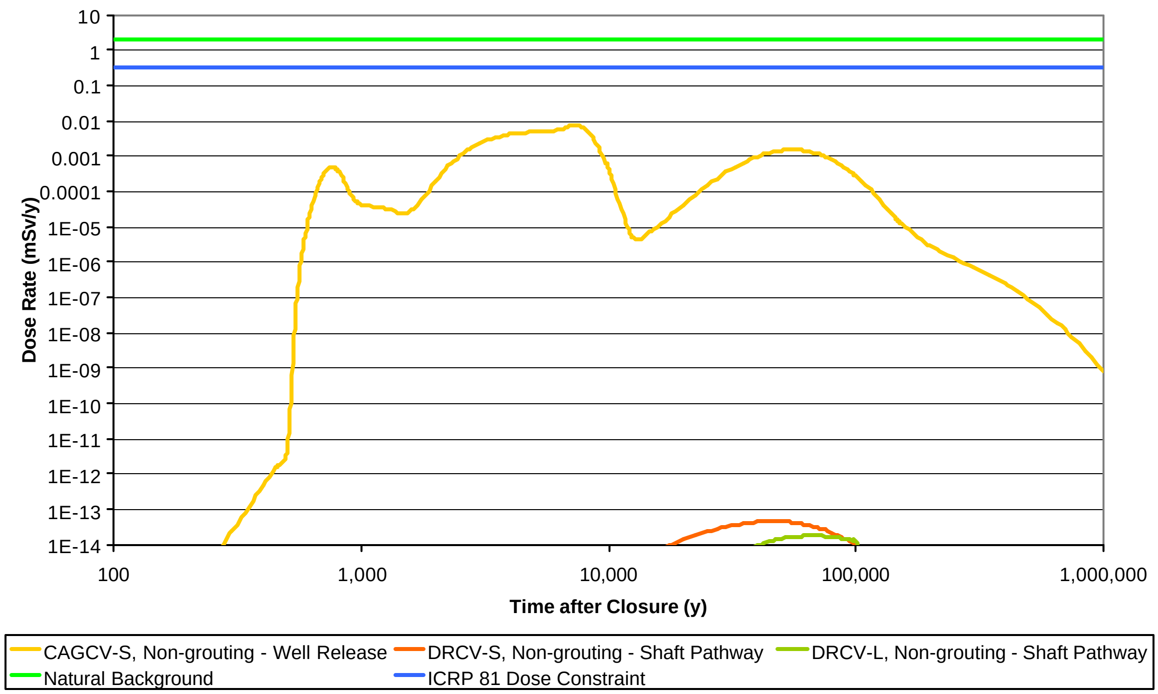

Figure 4: Calculated Dose Rates for the Most Significant Calculation Cases for the CAGCV and DRCV Concepts, Reference Scenario

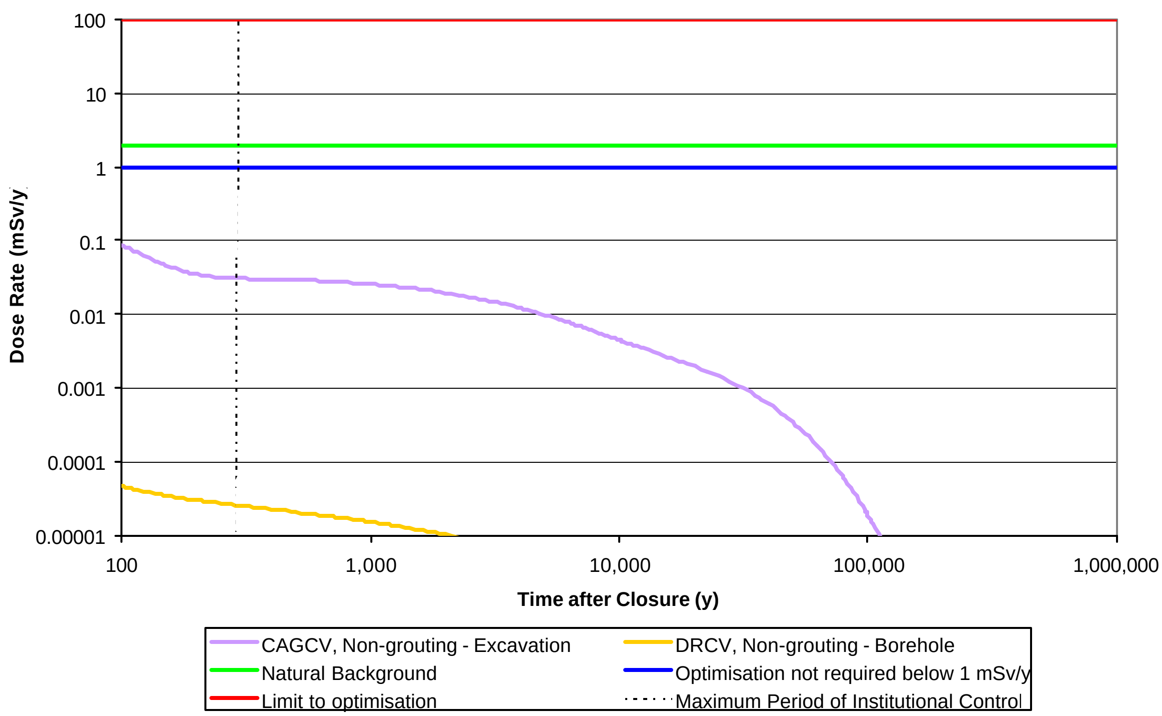

Figure 5: Calculated Dose Rates for the Most Significant Calculation Cases for the CAGCV and DRCV Concepts, Human Intrusion Scenario

8. RECOMMENDATIONS

The calculations for the preliminary post-closure radiological safety assessment were at a level consistent with the stage of the waste management programme and the information available. Should one of the repository options be considered further, the safety assessment will need to be updated to take account of future site-specific geotechnical investigations and design updates, and to include consideration of ILW.

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