IMPACT MODELLING FOR THE POSTCLOSURE SAFETY ASSESSMENT OF OPG'S DGR

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ABSTRACT

Ontario Power Generation (OPG) is proposing to build a Deep Geologic Repository (DGR) for Low and Intermediate Level Waste near the existing Western Waste Management Facility at the Bruce nuclear site in the Municipality of Kincardine, Ontario.

As part of the safety assessment for the proposed DGR, calculations were undertaken to evaluate the repository's potential postclosure impacts. Impacts were evaluated for a Normal Evolution Scenario, describing the expected long-term evolution of the repository and site following closure, and four Disruptive Scenarios, which consider events that could lead to possible loss of containment.

An assessment-level (system) model was implemented in AMBER, a compartment modelling code, that represents radioactive decay, waste package degradation, potential contaminant transport through the repository, sealed shafts, geosphere and surface environment, and the associated impacts. The model used input from detailed models implemented in the FRAC3DVS-OPG and T2GGM codes for the repository saturation, gas generation, and groundwater and gas flow processes.

Both safety and performance indicators were calculated to assess the potential impact of the DGR. Safety indicators include radiation dose to humans and environmental concentrations of radionuclides and non-radioactive hazardous substances. Performance indicators include contaminant amounts within various spatial domains (e.g., the repository, the host rock, and the wider geosphere) and fluxes of contaminants at various points in the DGR system.

The long timescales under consideration mean that there are uncertainties about the way the DGR system will evolve. In addition to assessing alternative future evolutions through different scenarios, uncertainties were addressed through the adoption of conservative assumptions, the evaluation of variant deterministic cases within each scenario, and probabilistic calculations.

The results for the Normal Evolution Scenario indicate that the DGR system provides effective containment of the emplaced contaminants. Most radionuclides decay within the repository or the deep geosphere. The amount of contaminants reaching the surface is very small, such that the maximum calculated dose for the Normal Evolution Scenario is more than five orders of magnitude below the public dose criterion of 0.3 mSv/a for all calculation cases. In addition, maximum calculated concentrations in the biosphere are well below the criteria for protection of biota from radionuclides, and for protection of humans and biota from non-radioactive contaminants. The isolation afforded by the location and design of the DGR limits the likelihood of disruptive events potentially able to bypass the natural and engineered barriers to a small number of situations with very low probability. Even if these events were to occur, the analysis shows that the contaminants in the waste would continue to be contained effectively by the DGR system such that the associated risk criterion is met.

1. INTRODUCTION

Ontario Power Generation (OPG) is proposing to build a Deep Geologic Repository (DGR) for Low and Intermediate Level Waste (L&ILW) near the existing Western Waste Management Facility at the Bruce nuclear site in the Municipality of Kincardine, Ontario. The DGR Project involves the construction, operation and eventual decommissioning of a repository situated nominally at 680 m below the Bruce nuclear site in an argillaceous limestone formation. More detailed information on the DGR Project can be found in companion papers [1-7].

A quantitative assessment of the postclosure (long-term) safety was conducted as part of an iterative process in conjunction with site characterization, waste characterization and facility design. This is documented in the Preliminary Safety Report [8] and the Preliminary Postclosure Safety Assessment Report [9].

2. APPROACH

Over 80% of the packaged waste volume is low-level waste. This decays within a few hundred years. However, some of the intermediate-level waste is hazardous for very long times. The safety strategy is to provide long-term isolation and containment through use of multiple barriers and passive systems, including in particular a stable geosphere.

The overall safety case and assessment approach and associated acceptance criteria are defined in the Preliminary Safety Reports [8,9], and summarized in the companion paper [7]. In particular, the long-term safety of the proposed facility is primarily assessed by considering its behaviour for a Normal Evolution Scenario, which describes the expected evolution of the repository, and four Disruptive Scenarios, which considers events that could lead to possible loss of containment. The scenarios assessed are summarized in Table 1. The assessment identifies a range of calculation cases with the aim of demonstrating that the DGR system is robust to the various sources of uncertainties (scenario, model and data).

This paper provides an overview of the postclosure impact modelling and results. In particular, it summarizes the associated models and data (Section 2), the calculated impacts for the Normal Evolution Scenario (Section 3), the calculated impacts for the Disruptive Scenarios (Section 4), the associated uncertainties (Section 5), and the overall conclusions arising from the impact modelling (Section 6).

Table 1. Scenarios evaluated in the postclosure safety assessment

Normal Evolution Scenario	The expected long-term evolution of the repository and site following closure. Over the 1 Ma assessment timescale, the scenario includes waste and packaging degradation, gas generation and build up, rockfall, earthquakes and, eventually, glacial cycles.	
Disruptive ("What if") Scenarios	Human Intrusion	Inadvertent intrusion into the DGR via an exploration borehole.
	Severe Shaft Seal Failure	Poorly constructed or substantially degraded shaft seal.
	Poorly Sealed Borehole	Poorly sealed or substantially degraded seals in site investigation/monitoring borehole.
	Vertical Fault	Transmissive vertical fault in the vicinity of the DGR.

3. MODELS AND DATA

3.1 Calculation cases

For each scenario, there is a calculation case which acts as a benchmark against which relevant acceptance criteria can be compared, and against which the variant calculation cases undertaken to investigate model and data uncertainties can be compared (Figure 1). For the Normal Evolution Scenario, the benchmark case is termed the "Reference Case"; for each Disruptive Scenario the benchmark case is termed the "Base Case" (to avoid ambiguity with the Normal Evolution Scenario Reference Case). The impacts for these Reference/Base Cases are presented in Section 3 (Normal Evolution Scenario) and Section 4 (Disruptive Scenarios).

3.2 Mathematical models and software implementation

The mathematical modelling approach used in the postclosure safety assessment is based on the use of an assessment-level (system) model incorporating all key processes relevant to contaminant release, transport and impact, supported by detailed models for the groundwater flow and transport, and gas generation and transport processes.

The assessment-level model is implemented in AMBER 5.3 [10]. This computer code represents contaminant transport within a compartment model approach. AMBER has been used in postclosure safety assessments of deep geologic repositories for radioactive waste in a 'total systems' manner [11]. The development of the mathematical models and their implementation has been undertaken under the project's quality plan and Quintessa's quality management system, which has been certified against the requirement of ISO 9001:2008.

The specific mathematical formulae used to represent the various release, migration and exposure mechanisms identified in the conceptual models are documented in the Normal Evolution and Disruptive Scenarios reports [12,13]. These have been implemented in four AMBER cases:

- a case file for the repository, shafts and geosphere model;
- a case file for the biosphere model; and
- variants of these two case files in which the radionuclides are replaced with non-radioactive contaminants.

The AMBER case files have been developed to represent contaminant release, movement, and impacts. AMBER does not calculate detailed water or gas flow. Rather, these are provided through the use of supporting detailed codes that explicitly solve such problems, with the results then being incorporated as input to the AMBER case files. The two detailed codes used in the postclosure safety assessment are FRAC3DVS-OPG [14] and T2GGM [15] (Figure 2), which are also summarized in the companion paper [16].

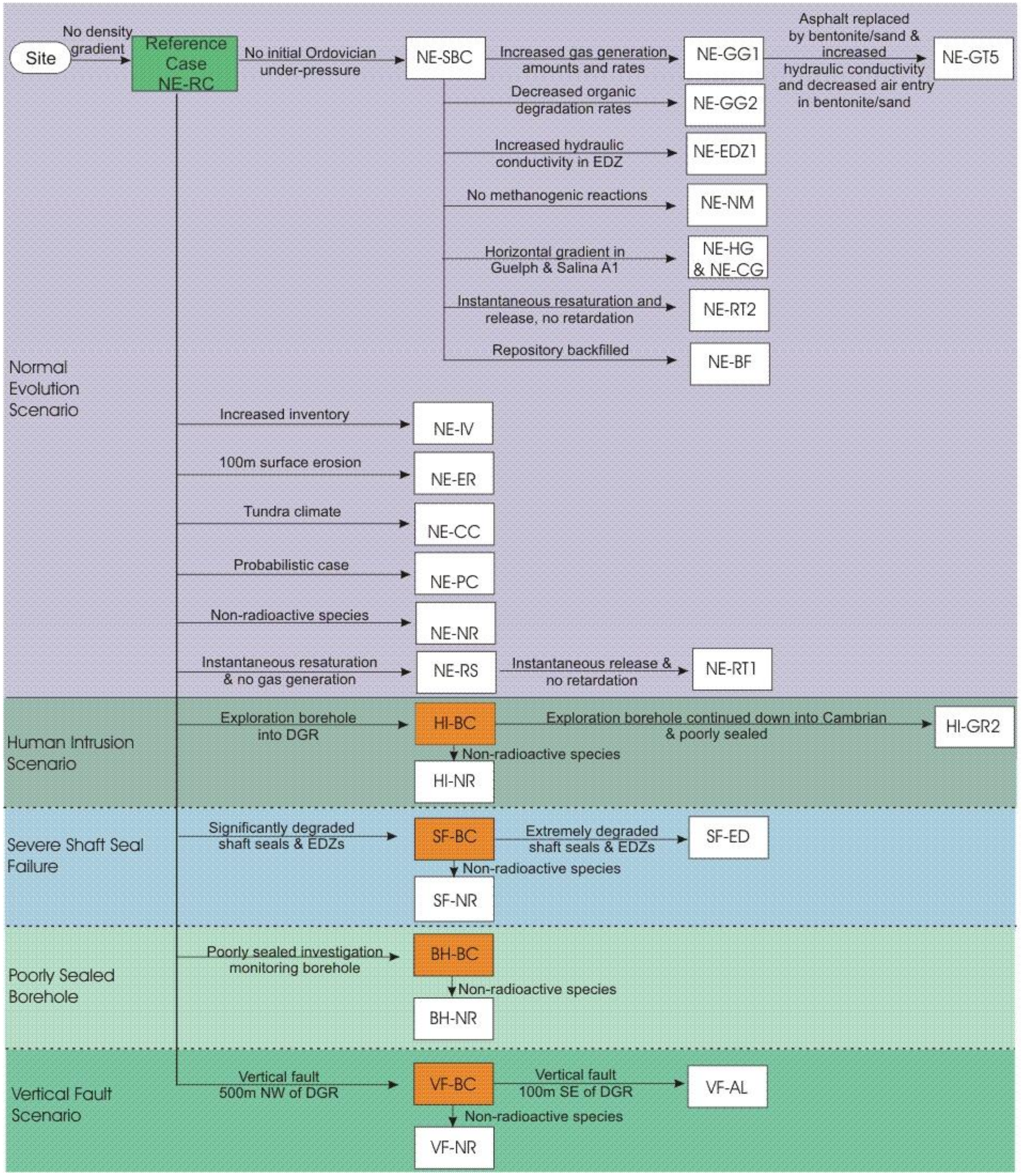


Figure 1. Impact modelling cases for the postclosure safety assessment

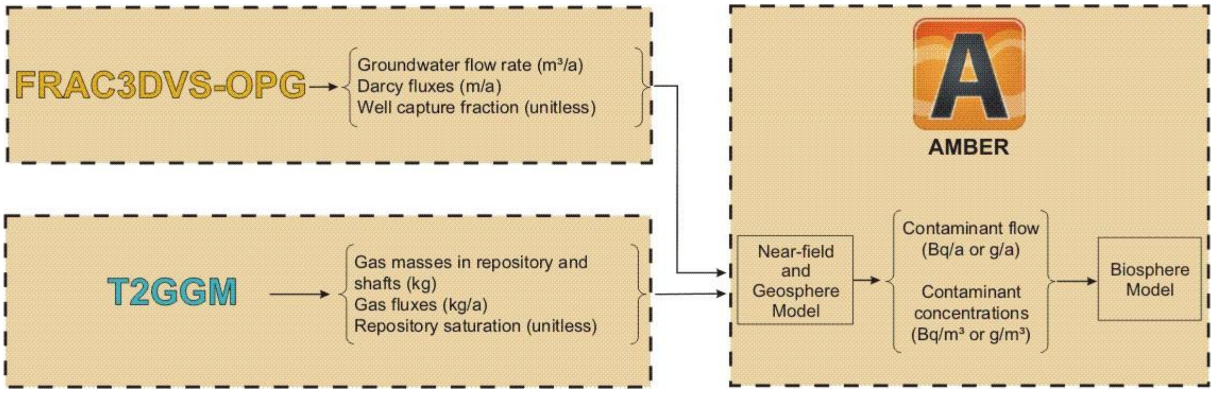


Figure 2. Information flow between the detailed groundwater (FRAC3DVS-OPG) and gas (T2GGM) codes and the assessment model (AMBER)

3.3 Data

Most of the data are specific to the DGR system and have been taken from its waste and site characterization programs. The overall DGR program has been structured such that the safety assessment has been produced in multiple iterations, with data freezes in synchronization with the inventory, design and geoscience programs.

Data required for safety assessment was either obtained from published literature or referenceable documents, or was released for use within the DGR project using a data clearance process. In the latter case, approved data have been documented using a data clearance form that records the persons providing and approving the dataset, together with the purpose and nature of the dataset, its status/history, and any limitations/restrictions on its use/application.

Table 2 summarizes the reference values used for the key parameters for the Normal Evolution Scenario's Reference Case. Further details on model parameters used in this safety assessment are provided in the Data report [17], or the associated modelling reports.

4. NORMAL EVOLUTION SCENARIO

4.1 Containment in the Repository

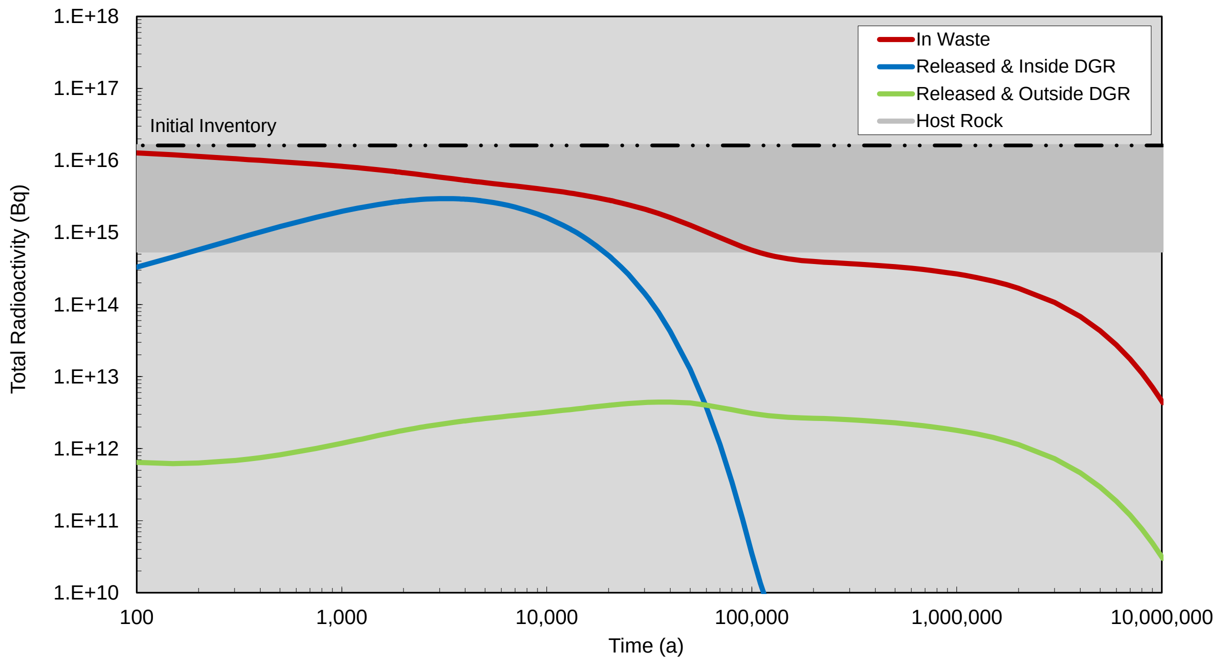
The important initial behaviour of the repository is the slow in-seepage of water from the rock, and the slow degradation of waste and containers leading to build up of gas. The balance of these processes leads to low amounts of water within the repository, with the repository remaining essentially dry for a period in excess of a million years. However, there is sufficient water available from the host rock in this case to sustain corrosion and degradation reactions.

Table 2. Reference values for key parameters for the Normal Evolution Scenario

Parameter	Value(s)
Repository	
Repository depth	680 m
Number of emplacement rooms	Panel 1: 14; Panel 2: 17
Volume of emplacement rooms	Panel 1: 1.7 x 10^5 m^3; Panel 2: 2.5 x 10^5 m^3
Average width of emplacement rooms	Panel 1: 8.25 m; Panel 2: 8.5 m
Average repository room/tunnel height	7 m
Panel 1 access tunnels dimensions	L 537 m, W 5.4 m, H 7.0 m
Panel 2 access tunnels dimensions	L 787 m, W 5.9 m, H 7.0 m
Monolith dimensions (within repository)	L 85 m, W 11.8 m, H 7.0 m (from open access tunnels to base of a combined shaft)
Monolith dimensions (within shafts)	Radius 5.9 m; H 13 m (from repository ceiling level upwards)
Panel footprint	2.4 x 10^5 m^2
Excavated volume	Excavated: 5.3 x 10^5 m^3; Void: 4.2 x 10^5 m^3.
Waste volume (as disposed)	Panel 1: 6.8 x 10^4 m^3 ; Panel 2, 1.3 x 10^5 m^3
Waste inventory	8.8 x 10^2 TBq LLW, 1.6 x 10^4 TBq ILW at 2062
Mass of organics (waste, packages & engineering)	2.2 x 10^7 kg
Mass of concrete (waste, packages & engineering)	2.1 x 10^8 kg (includes monolith)
Mass of metals (waste, packages & engineering)	6.6 x 10^7 kg
Backfilling of rooms and tunnels	None except monolith in immediate vicinity of shafts
Monolith properties	K_h and K_v 1 x 10^{-10} m/s; porosity 0.1; effective diffusion coefficient 1.25 x 10^{-10} m^2/s (degraded from closure)
Repository HDZ	K_h 1 x 10^{-6} m/s, $K_v = K_h$; porosity 4 x rock mass Emplacement rooms and tunnels: 0.5 m thick above/below and sides Supported tunnels: 2 m thick above/below, 0.5 m thick sides
Repository EDZ	K_h 10^3 x rock mass, $K_v = K_h$; porosity 2 x rock mass Emplacement rooms and tunnels: 8 m thick above/below and sides Supported tunnels: 3 m thick above/below and sides
Rockfall	Rockfall affects all rooms and tunnels,10 m into ceiling immediately after closure
Corrosion rates	Carbon steel and galvanized steel: 1 μm/a(unsaturated), 2 μm/a(saturated), Passivated carbon steel, stainless steel and Ni-alloys: 0.1 μm/a Zr-alloys: 0.01 μm/a
Degradation rates	Cellulose: 5 x 10^{-4} /a Ion exchange resins, plastics and rubber: 5 x 10^{-5} /a
Solubility and sorption in repository	Solubility limitation only considered for aqueous C releases (0.6 mol/m^3). No sorption considered
Shaft	
Internal diameter (lower section)	Main: 9.15 m; Ventilation: 7.45 m; Combined: 11.8 m (concrete lining and HDZ removed)
Length (lower section)	483.5 m (top of monolith to top of bulkhead at top of intermediate groundwater zone)
Internal diameter (upper section)	Main: 6.5 m; Ventilation: 5.0 m
Length (upper section)	178.6 m (top of upper bulkhead to ground surface)
Backfill and seals	Sequence of bentonite-sand, asphalt, LHHPC and engineered fill. LHHPC bulkheads (degraded from closure) keyed across the inner EDZ
Vertical and horizontal hydraulic conductivity	Bentonite-sand: 1 x 10^{-11} m/s; Asphalt: 1 x 10^{-12} m/s; LHHPC: 1 x 10^{-10} m/s; Engineered fill: 1 x 10^{-4} m/s
Diffusion and transport porosity	Bentonite-sand: 0.3; Asphalt: 0.02; LHHPC: 0.1; Engineered fill: 0.3

Parameter	Value(s)
Effective diffusion coefficient	Bentonite-sand: 3 x 10^{-10} m^2/s; Asphalt: 1 x 10^{-13} m^2/s; LHHPC: 1.25 x 10^{-10} m^2/s; Engineered fill: 2.5 x 10^{-10} m^2/s
EDZ	Inner EDZ, 0.5 x shaft radius thick, K_v x 100 rock mass, $K_h = K_v$; porosity 2 x rock mass Outer EDZ, 0.5 x shaft radius thick, K_v x 10 rock mass, $K_h = K_v$; porosity = rock mass
Sorption in shaft and EDZ	Conservative estimates for Zr, Nb, Cd, Pb, U, Np and Pu. Zero for all others.
Geosphere	
Host rock type	Low permeability argillaceous limestone (Cobourg Formation)
Temperature at repository depth	22 °C
Groundwater composition at depth	Na-Ca-Cl dominated brine; TDS: 131-375 g l^{-1}; pH: 6.5 to 7.3; Eh: reducing
Hydraulic heads	+165 m at top of the Cambrian sandstone Variable head profile with underpressures in the Ordovician (up to -290 m) 0 m at the top of the Lucas Formation (top of the shallow groundwater zone)
Deep groundwater zone:	
horizontal hydraulic conductivity	8 x 10^{-15} to 4 x 10^{-12} m/s for most formations; 1 x 10^{-9} in the Shadow Lake Formation and 3.0 x 10^{-6} in the Cambrian sandstone
vertical hydraulic conductivity	10% of horizontal hydraulic conductivity for most formations; 0.1% for Coboconk and Gull River formations; isotropic for Cambrian
transport porosity	0.009 to 0.097
effective diffusion coefficient	2.2 x 10^{-13} to 2.4 x 10^{-11} m^2/s (some anisotropy)
horizontal hydraulic gradient	0
Intermediate groundwater zone:	
horizontal hydraulic conductivity	5 x 10^{-14} to 2 x 10^{-7} m/s
vertical hydraulic conductivity	10% of horizontal hydraulic conductivity for most formations; Isotropic for Guelph Formation and Salina A1 Unit upper carbonate
transport porosity	0.007 to 0.2
effective diffusion coefficient	3 x 10^{-14} to 6.4 x 10^{-11} m^2/s (some anisotropy)
horizontal hydraulic gradient	0
Shallow groundwater zone:	
horizontal hydraulic conductivity	1 x 10^{-7} to 1 x 10^{-4} m/s
vertical hydraulic conductivity	10% of horizontal hydraulic conductivity for all formations
transport porosity	0.057 to 0.077
effective diffusion coefficient	6 x 10^{-12} to 2.6 x 10^{-11} m^2/s
horizontal hydraulic gradient	0.003
Sorption in geosphere	Conservative estimates for Zr, Nb, Cd, Pb, U, Np and Pu. Zero for all others.
Biosphere	
Average annual surface temperature	8.2 ºC
Average total precipitation	1.07 m/a
Ecosystem	Temperate
Groundwater release paths	1) 80 m deep well located 500 m down gradient of combined shaft. Well demand of 6388 m^3/a for self-sufficient farm with crop irrigation. 2) near-shore lake bed (for discharge from shallow groundwater zone)
Gas release paths	Soil and House located above repository
Receptor (Critical Group)	Site resident, living on repository site and farming. Habit data based on CSA N288.1 [18]
Human dose coefficients	See Section 7.2 of Data report [17]
Abbreviations used in the table: K_v: vertical hydraulic conductivity K_h: horizontal hydraulic conductivity HDZ: Highly Damage Zone	LHHPC: Low Heat High Performance Cement TDS: Total Dissolved Solids EDZ: Excavation Damage Zone L: Length W: Width H: Height

Although the waste containers are not considered to be long-lasting, the combination of slow saturation of the repository, slow degradation of some wastes, and slow diffusion from the repository into the surrounding rock provides effective containment. This is illustrated in Figure 3, which shows the amount of radioactivity in the waste, the amount released from the waste but remaining within the DGR, and the amount released from the DGR to the host rock and shafts. The figure shows that the amount of radioactivity outside the waste reaches a maximum of 18% of the initial inventory. This is due to the release of C-14 (from resins) as gas within the DGR. The amount of radioactivity outside the DGR reaches a maximum of 0.03% of initial inventory.



Notes: Horizontal grey band is the range of natural rock radioactivity above the repository. Lower level is repository footprint area, upper level is the Bruce nuclear site area. The figure uses a grey background for the period beyond one million years to emphasize the illustrative nature of the results over such timescales.

Figure 3. Total Radioactivity Within and Outside Repository for the Normal Evolution Scenario Reference Case

4.2 Release of contaminants via the geosphere and shafts

The host rock surrounding the DGR has very low permeability, such that there is no advection of groundwater, and contaminants can only diffuse away from the repository.

Figure 4 shows the total calculated radionuclide concentrations in the formations above the DGR for the Reference and Simplified Base Cases. The concentrations decline with distance from the DGR, such that calculated peak concentrations in the rock are comparable to the natural background radioactivity in the Cobourg and Collingwood (mostly K-40 and U-238), and do not exceed 1 Bq/m^3 beyond the Queenston Formation (~450 m depth).

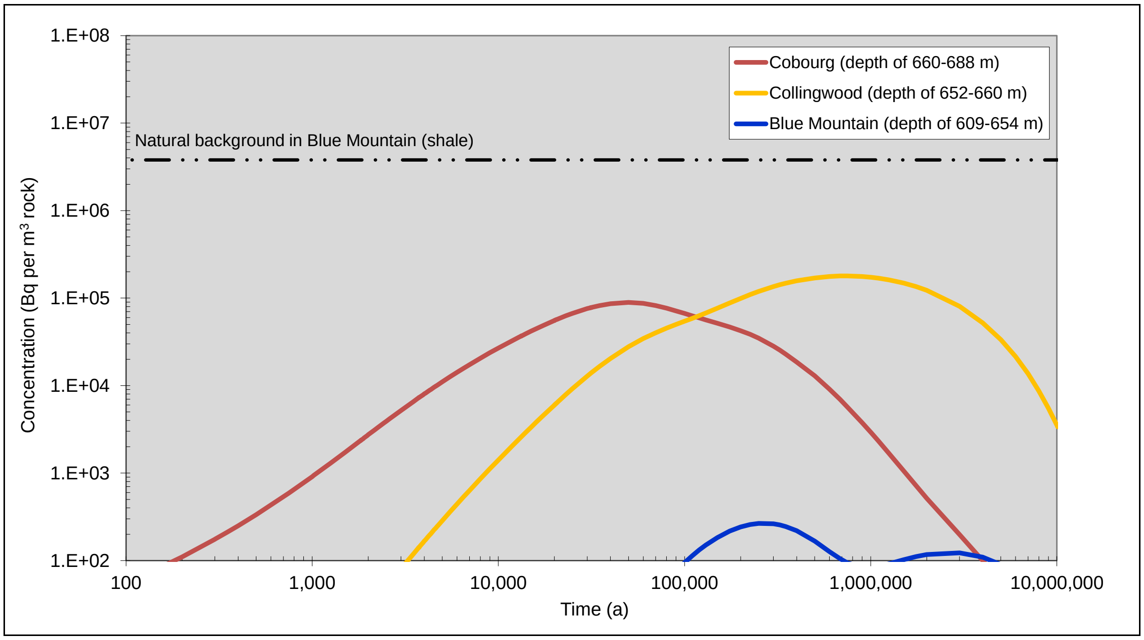


Figure 4. Radionuclide concentration in the deep groundwater zone for the Normal Evolution Scenario's Reference Case

Figure 5 shows the calculated concentrations in the shaft sealing materials and demonstrates their effectiveness at minimizing contaminant transport. The figure shows that concentrations are reduced to very small levels. No concentrations greater than 1 Bq/m^3 are calculated for the seals above the top of the Manitoulin Formation (~435 m depth).

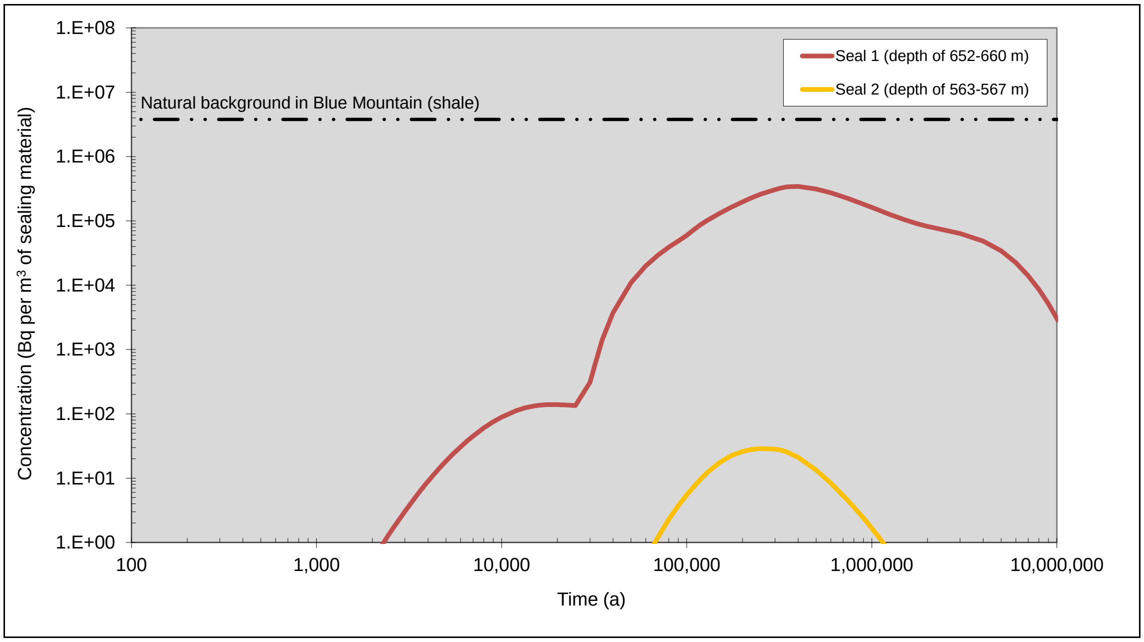


Figure 5. Radionuclide concentration in shaft for the Normal Evolution Scenario Reference Case

The low and slow level of repository resaturation, combined with the very low permeability of the host rock and the shaft seals, means that effectively no contamination enters the shallow groundwater zone and then the biosphere. The maximum calculated flux of less than 10^{-5} Bq/year does not occur until well beyond a million years and is dominated by long lived I-129. Fluxes of non-radioactive contaminants peak over similar times with Ni being the main contributor to the maximum flux of 0.03 g/year.

4.3 Calculated impacts

The very small release of contaminants to the biosphere results in negligible concentrations in biosphere media, less than 10^{-10} Bq/kg or Bq/L for soils or well or surface waters. For comparison, surface waters have a provincial background concentration of around 0.1 Bq/L gross-beta. Lake sediments have naturally occurring K-40 of around 250 Bq/kg, and soils have provincial background concentrations of K-40 of around 500 Bq/kg. The maximum calculated dose to the site resident resulting from these small concentrations is many orders of magnitude lower than the dose criterion for the Normal Evolution Scenario of 0.3 mSv/year.

The calculated radionuclide concentrations in the biosphere for the Reference Case are much smaller than the screening no-effect concentrations (NECs) for impacts on non-human biota. The calculated concentrations of non-radioactive contaminants in biosphere media are also much smaller than the environmental quality standards for groundwater, soils, surface water and sediments designed to protect human health and the environment.

5. DISRUPTIVE SCENARIOS

5.1 Inadvertent Human Intrusion

Land use controls and other measures after closure should prevent future deep drilling or excavation at the repository site. However, if the presence of the repository was to be forgotten and a deep drilling program was carried out at the site, the exploration borehole could reach the DGR, contaminants could be released to the surface and result in human exposure.

A wide variety of exposure pathways could occur for this scenario, so a range of potential receptors has been assessed – the drill crew and nearby residents (i.e., within 100 m of the drill site) exposed during the drilling, laboratory technicians exposed to the core sample, and future site residents exposed to soil contaminated with the extracted core. Calculated doses for these people are shown in Figure 6. The calculated dose to the drill crew peaks at about 1 mSv due to exposure to Nb-94 in the drill core debris. The calculated dose to the nearby resident peaks at about 0.1 mSv due to inhalation of C-14 released from the borehole. The dose to the future site resident is dominated by external irradiation from Nb-94 and peaks around the dose criterion for Disruptive Scenarios of 1 mSv/year.

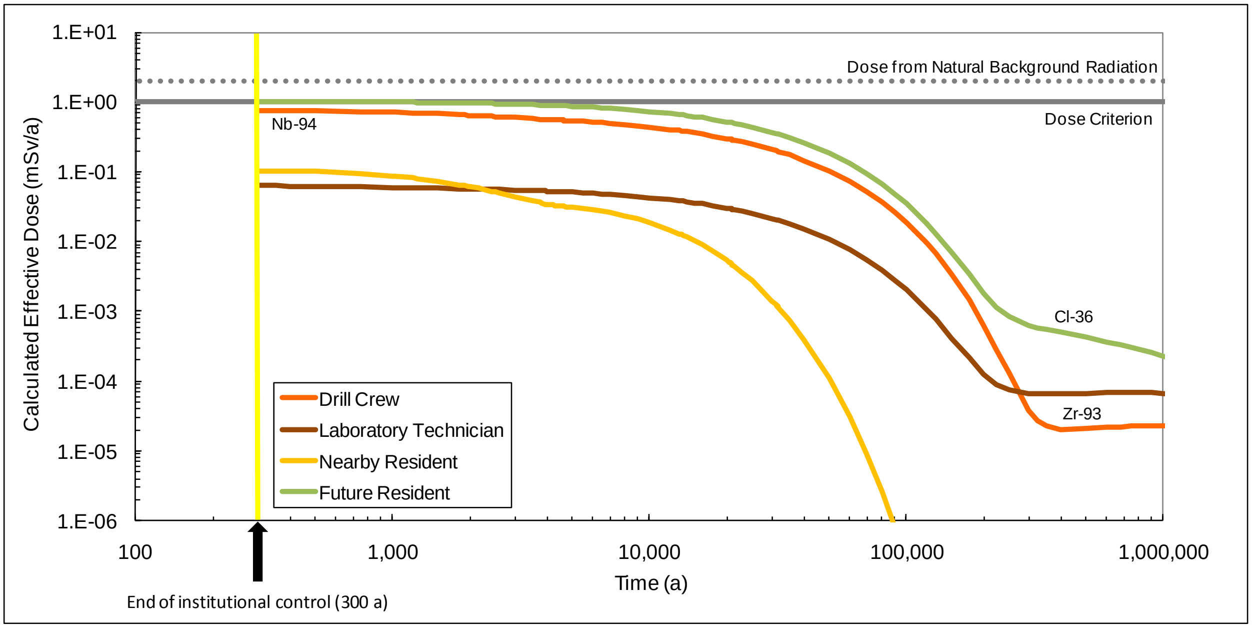


Figure 6. Calculated Effective Doses from Surface Releases for the Human Intrusion Scenario's Base Case, as a Function of the Time of Intrusion

The likelihood of inadvertent human intrusion is low due to the depth of the repository and the absence of any known commercially viable resources in the region around the repository. While it is not possible to predict the likelihood of intrusion, the scenario is estimated to have an annual probability of occurrence of about 10^{-5}/year based on current deep drilling practices and simple estimates (Quintessa and SENES 2011). Over long time scales, it becomes likely – however, the potential dose impacts also decrease over long times, and in particular intrusion impacts fall below the dose criterion after about 10,000 years. Based on a probability of 10^{-5}/year, a peak dose of 1 mSv and a health risk of 0.057/Sv [19], the associated risk is around 6 x 10^{-10} serious health effects per year, well below the reference health risk value of 10^{-5}/year.

Calculations of the concentration of non-radioactive contaminants in soils contaminated by the drill core indicate that environmental quality standards are not exceeded. Comparison of radionuclide concentrations in biosphere media show that C-14 and Nb-94 exceed the screening criterion for biota by about a factor of 20 within the site assuming the contaminated drill core debris is left on site, while all other radionuclides are below their criteria. Since this intrusion is very unlikely, leaving drilling debris on site is against current regulations, and any exposure is localized around the drill site, the risk is low. Furthermore, less conservative Ecological Risk Assessment calculations show that the resulting doses to site-specific biota are around 3% of relevant dose criterion.

5.2 Severe Shaft Seal Failure

The shaft seal includes several materials that act individually and collectively as a barrier to contaminant transport. The Severe Shaft Seal Failure Scenario assesses a hypothetical situation in which there is a major breakdown in the performance of these barriers. For the Base Case, the hydraulic conductivity of all shaft seals are conservatively set at 10^{-9} m/s (i.e., much higher than the design values of around 10^{-11} m/s). The degradation is assumed to be present at time of closure and affect the entire 500 m of low-permeable shaft seal.

The degraded shaft seals permit more rapid water inflow into the repository. The resulting gas generation and reduced shaft seal capability allows the repository gas pressure to open a pathway after about 20,000 years that enables the repository gas to vent up the shafts. The bulk gas, which carries C-14 labelled gases from the DGR, reaches the shallow geosphere zone. About 95% of the peak gas flux to the shallow groundwater zone reaches the biosphere as free gas with the remainder dissolving in the groundwater.

The calculated dose to the site resident reaches a maximum of around 1.1 mSv/year after about 23,000 years (see Figure 7) but falls rapidly thereafter. The dominant exposure pathways are inhalation within a house positioned directly above the main shaft, and ingestion of plant produce, each of which contributes about 40% of the calculated peak dose. It is noted that a scenario likelihood of less than 10^{-1} per year would result in the risk of serious health effects being less than the reference value of 10^{-5}/year. The probability of (fast) severe shaft seal degradation combined with a house positioned directly above one of the shafts can reasonably be considered to be significantly lower than 10^{-1} per year.

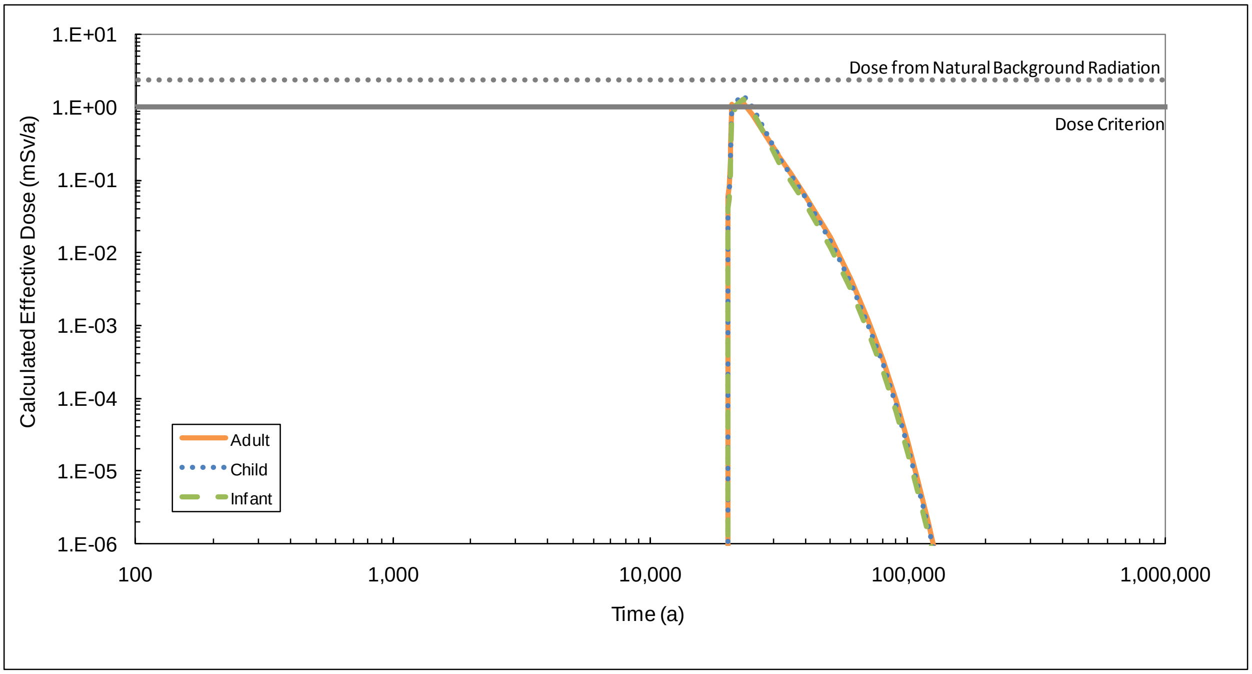


Figure 7. Calculated Effective Dose to Site Resident for the Severe Shaft Seal Failure Scenario Base Case

Calculated concentrations in biosphere media (soils, surface water, and sediment) remain relatively low for the Base Case. The peak calculated concentrations for C-14 in soils and sediments remain below the NECs for protection of non-human biota. The peak calculated C-14 concentration in local surface water of 0.3 Bq/L is a factor of 1.4 above the associated screening criteria for biota. However, shaft seal failure is an unlikely scenario and these consequences would only apply if the failure is within about 50,000 years after DGR closure (due to C-14 decay). Also, the high concentration is in the local stream, and is slightly above the screening criterion. Based on these considerations, and the conservatism in the screening criterion, the actual risk to biota is low. Calculated biosphere concentrations for all other radionuclides are more than seven orders of magnitude below their associated criteria.

There is a negligible release of non-radioactive contaminants via the groundwater pathway, and all calculated values are many orders of magnitude below the environmental quality standards.

5.3 Poorly Sealed Borehole

Detailed modelling indicates that a poorly sealed borehole has limited influence on the hydraulic conditions at the repository horizon because of the very low permeability host rock around the DGR.

The calculations are based on a repository that is resaturated at closure, which maximizes the release of contaminants to groundwater. Figure 8 shows the calculated radionuclide transfer flux to the shallow groundwater zone via the borehole. Calculated concentrations in biosphere media of radionuclides and non-radionuclides are very small. The calculated dose to an adult site resident is very small, peaking at 4 x 10^{-8} mSv/year after about 900,000 years, much lower than the 1 mSv/year dose criterion.

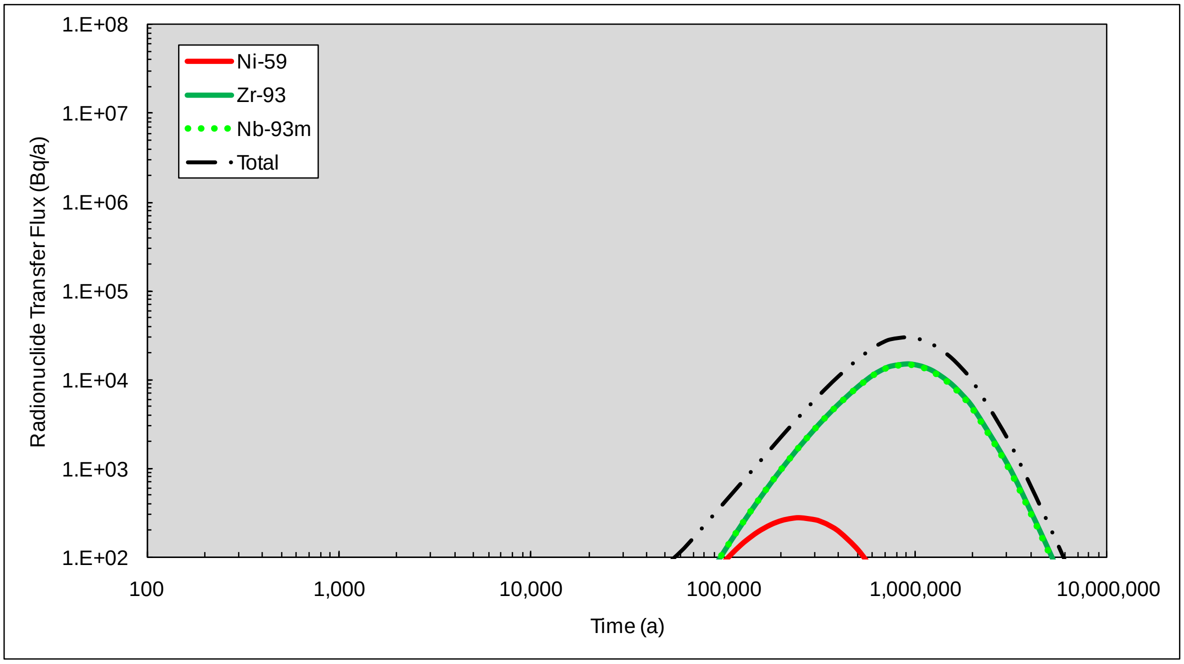


Figure 8. Calculated radionuclide flux from the borehole to the shallow groundwater zone for the Poorly Sealed Borehole Scenario Base Case

5.4 Vertical Fault

The Vertical Fault Scenario's Base Case considers "what if" a fault exists 500 m from the repository, just outside the well-characterized site area. The detailed groundwater modelling shows that the fault only has a minor impact on the hydraulic conditions in the repository. Since any vertical fault would connect to the pressurized Cambrian, a pressure gradient develops which directs groundwater movement away from the fault. Contaminants in the repository need to diffuse either directly to the fault (against the hydraulic gradient) or downwards to the Cambrian and then via groundwater flow to the fault, before they can be transported by groundwater advection up the fault to the Guelph Formation. The results indicate that the resulting radionuclide transfer flux to the Guelph peaks at about 3 MBq/year after more than one million years (Figure 9).

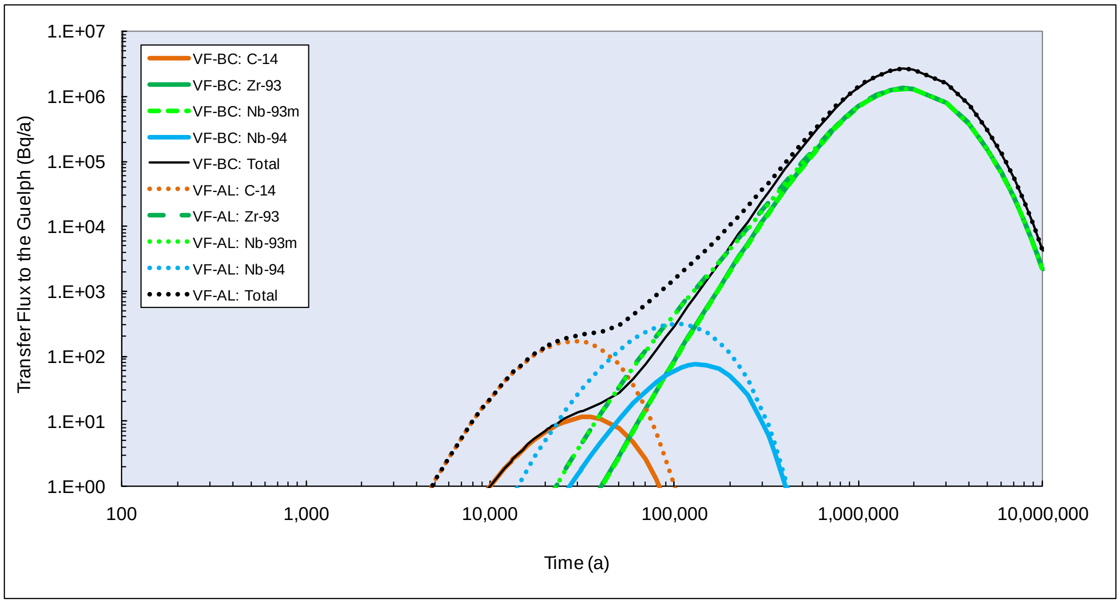


Figure 9. Calculated radionuclide flux from the fault to the Guelph Formation for the Vertical Fault Scenario Base Case

Horizontal groundwater flow in the Guelph is assumed to discharge to the near-shore of the lake. The resulting dispersion means that calculated radionuclide and non-radionuclide concentrations are several orders of magnitude smaller than the criteria for humans and biota. The peak calculated effective dose to the maximally exposed group (the site shore resident) is 5×10^{-10} mSv/year after more than a million years, much smaller than the dose criterion.

6. ASSESSMENT OF UNCERTAINTIES

6.1 Future Uncertainties

The uncertainty in the future evolution of the site and repository is tested with the Normal Evolution Scenario and the four Disruptive Scenarios. Very low contaminant release to the shallow groundwater zone and negligible annual dose are calculated for the Normal Evolution Scenario (orders of magnitude below the dose criterion of 0.3 mSv/year). For the Disruptive Scenarios, the calculated doses for the Human Intrusion and Severe Shaft Seal Failure cases are at or just below the dose criterion of 1 mSv/year for times up to about 30,000 years. However, when the low likelihood of such scenarios is taken into account, the risk benchmark of 10^{-5} health effects per year is not exceeded. The maximum calculated doses for the Poorly Sealed Borehole and Vertical Fault Scenarios remain well below the dose criterion.

"What-if" variant calculations for the Disruptive Scenarios indicate that doses of tens of mSv would require either:

- that the intrusion borehole is continued on past the repository and down into the pressurized Cambrian formation and that the borehole is not appropriately sealed, allowing for long-term flow of water from the Cambrian through the repository and then to the shallow groundwater zone; or
- that the entire shaft seal system (500 m of low-permeable material) would have to degrade to an effective conductivity of around 10^{-7} m/s, roughly equivalent to very fine sand and silt.

In both cases, the doses would apply to someone living directly on the repository site; impacts further afield (i.e., off the Bruce nuclear site) would be much lower.

6.2 Model and Data Uncertainties

Model and data uncertainties associated are addressed through the evaluation of a set of calculation cases designed to bound the effects of these uncertainties for the Normal Evolution Scenario. The following uncertainties are evaluated:

- repository resaturation;
- waste inventory;
- contaminant release rate;
- gas generation;
- geosphere gas properties;
- geosphere transport properties;
- shaft seal performance;
- geosphere over- and underpressures;
- geosphere horizontal flow;
- human receptors; and
- glaciation.

The resulting maximum calculated doses are summarized in Figure 10. The main factors that could cause higher dose compared to the Reference Case are fast resaturation (which neglects the rock low permeability and gas generation), instant release and no sorption of all contaminants, and assumptions leading to higher gas generation coupled with degraded shaft seals. However, the figure shows that the maximum calculated dose for all calculated cases is more than five orders of magnitude below the 0.3 mSv/a dose criterion. Calculated doses within the shaded range can be considered to be negligible.

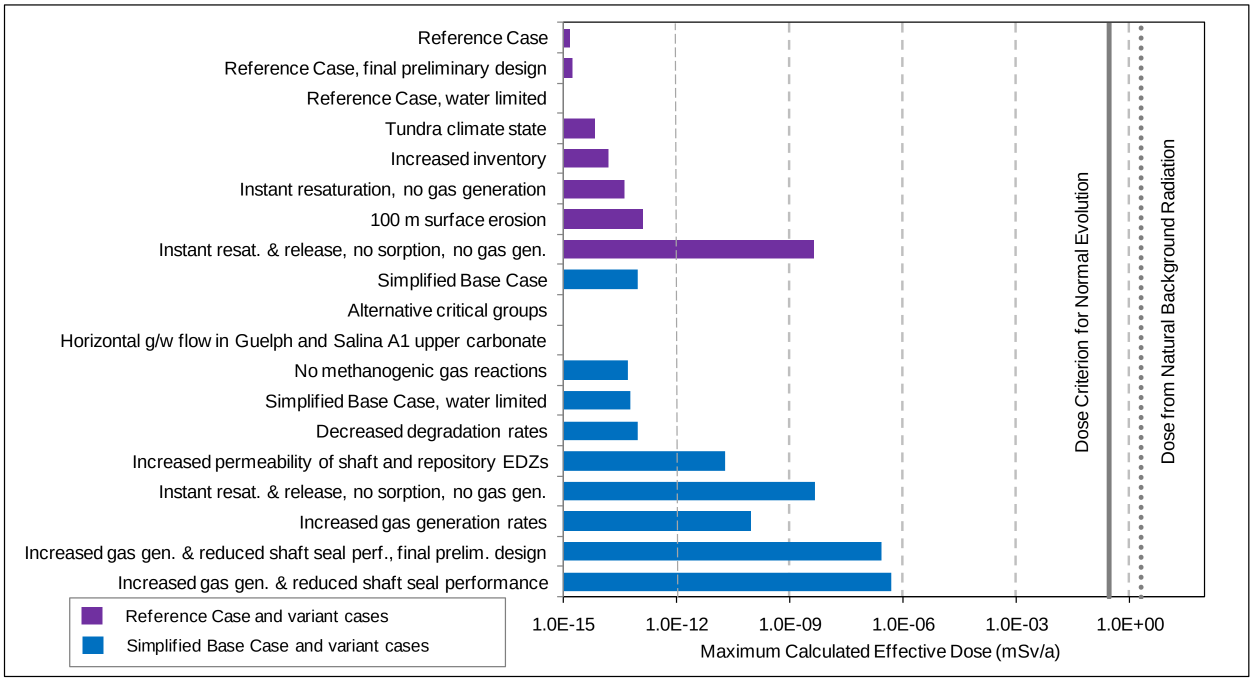


Figure 10. Maximum Calculated Doses for the Normal Evolution Scenario's Calculation Cases

7. CONCLUSIONS

The postclosure safety assessment has evaluated the DGR's ability to perform in a manner that will protect human health and the environment from the emplaced waste for an expected evolution scenario, as well as a number of disruptive scenarios.

The assessment calculations for the Normal Evolution Scenario indicate that the DGR system provides effective containment of the emplaced contaminants. Most radionuclides decay within the repository or the deep geosphere. The amount of contaminants reaching the surface is very small, such that the maximum calculated impacts for the Normal Evolution Scenario are much less than the public dose criterion of 0.3 mSv/year for all calculation cases. In addition, potential impacts of radionuclides on biota and non-radioactive contaminants on humans and non-human biota are well below the relevant criteria.

The isolation afforded by the location and design of the DGR limits the likelihood of disruptive events potentially able to bypass the natural barriers to a small number of situations with very low probability. Even if these events were to occur, the analysis shows that the contaminants in the waste would continue to be contained effectively by the DGR system such that the associated risk criterion is met.

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