Postclosure Assessment Modelling of a Deep Geologic Repository for Low and Intermediate Level Radioactive Waste in Ontario, Canada - 15145

Russell C Walke*, Richard H Little*, Helen Leung**
* Quintessa Limited, The Hub, 14 Station Road, Henley-on-Thames, Oxfordshire RG9 1AY, UK (russellwalke@quintessa.org).
** Nuclear Waste Management Organization (NWMO), 22 St. Clair Avenue East, Sixth Floor, Toronto, Ontario M4T 2S3, Canada.

ABSTRACT

In 2011, Ontario Power Generation (OPG) submitted an Environmental Impact Statement and a Preliminary Safety Report (PSR) to the federal authorities in Canada to support an application for a site preparation and construction licence for a Deep Geologic Repository (DGR) for low and intermediate level radioactive waste (L&ILW). The DGR, which is proposed to be located close to the existing Western Waste Management Facility (WWMF) at the Bruce nuclear site, would receive L&ILW arising from the operation and refurbishment of OPG's nuclear reactors; the wastes are currently stored safely at the WWMF. The PSR is supported by postclosure safety assessment modelling, including a total-systems level model implemented in the AMBER compartment modelling software that draws directly on detailed groundwater and coupled groundwater and gas modelling using the FRA3DVS-OPG and TOUGH2 codes. A full suite of calculation cases is managed within a single AMBER model, which aided efficient management of the calculation files and quality assurance. Assessment of expected/normal evolution cases results in maximum calculated effective doses to humans that are more than five orders of magnitude below associated criteria. Assessment of conservative disruptive and 'what if' scenarios results in maximum calculated doses that are higher than those for the normal evolution cases, but which, when the low likelihood of occurrence is taken into account, remain significantly below the associated risk criterion. The assessment demonstrates that deep geologic repositories can provide a safe disposal option and provides an example of evaluating the safety of projects on long time scales. It shows how results from detailed groundwater and gas codes can be incorporated into assessment-level codes such as AMBER, thereby providing a single systems model that can be used to efficiently evaluate a wide range of scenarios and associated calculation cases.

INTRODUCTION

In 2011, Ontario Power Generation (OPG) submitted an Environmental Impact Statement [1] and a Preliminary Safety Report (PSR) [2] to the federal authorities in Canada to support an application for a site preparation and construction licence for a Deep Geologic Repository (DGR) for low and intermediate level radioactive waste (L&ILW). The DGR, which is proposed to be located close to the existing Western Waste Management Facility (WWMF) at the Bruce nuclear site (Fig. 1), would receive L&ILW arising from the operation and refurbishment of OPG's nuclear reactors; the wastes are currently stored safely at the WWMF.

Fig. 1. Location of the Bruce Nuclear Site, Ontario, Canada

The PSR demonstrates that the DGR can be safely constructed and operated and would remain safe on time scales after closure during which the wastes remain hazardous to human health and the environment. A postclosure safety assessment is one of a suite of studies that supports the PSR. The assessment is documented in an over-arching report [3] that draws on supporting reports (see Fig. 2).

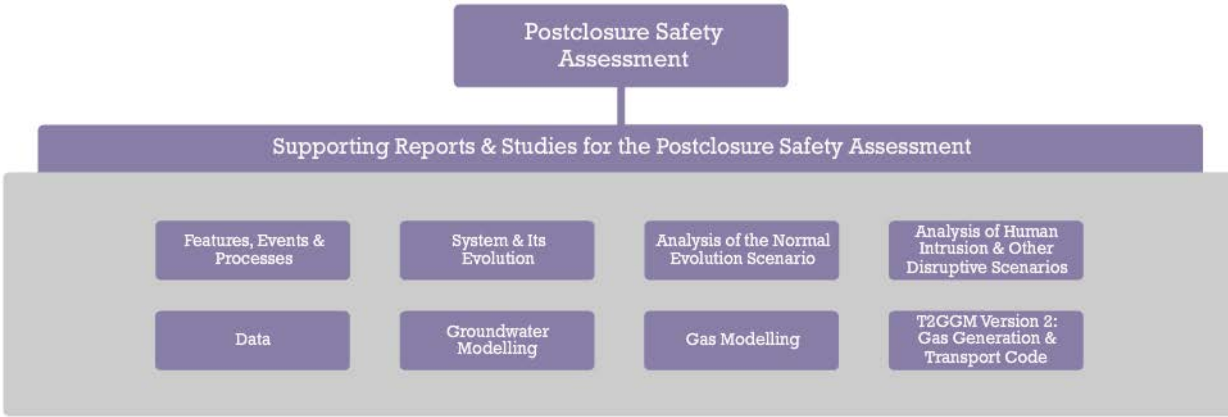

Fig. 2. Postclosure Safety Assessment Reports for the DGR

CONTEXT

Evaluation of the long-term safety of the DGR is needed to demonstrate compliance with the regulatory criteria required to obtain a site preparation and construction licence in Canada [4]. Quantitative assessments based on understanding of the wastes, engineering, geoscience and long-term environmental change are one of the components that help to build confidence in the proposed facility. Due to the inherent uncertainties when projecting the behaviour of repositories into the long-term future, the assessments must be seen to demonstrate reasonable confidence in the long-term safety and not as predictions of actual impact. Different types of uncertainty are explicitly managed in the assessment, for example, through assessing safety under a range of potential future scenarios, encompassing the expected evolution as well alternative worst case and 'what if' situations. Other uncertainties are managed using conservative assumptions that err on the side of overestimating potential impacts, for example, no credit is taken for packaging and closure walls, and no sorption or solubility limitation is accounted for in the repository.

REPOSITORY CONCEPT

The proposed repository concept centres around 31 emplacement rooms arranged in two panels approximately 680 m below ground surface in a competent, tight Ordovician limestone formation (see Fig. 3). The proposed repository is accessed via two vertical shafts and includes underground service areas, access and ventilation tunnels. The operational and refurbishment wastes would be emplaced without backfill; emplacement rooms and access tunnels will be sealed with closure walls. Upon closure of the facility, the base of the shafts will be sealed with a concrete 'monolith' and the shafts sealed with bentonite-sand and asphalt based materials along with a sequence of concrete bulkheads. The proposed DGR is overlain by sequences of low permeability shales and dolostones, with the Ordovician formations above the repository exhibiting under-pressures that act as a further barrier to groundwater transport towards the near-surface. The groundwater at and above the proposed depth of the DGR is highly saline, with fresh groundwater only being encountered within about 80 m of the ground surface where there is flow towards Lake Huron, which is about 1 km from the main shaft.

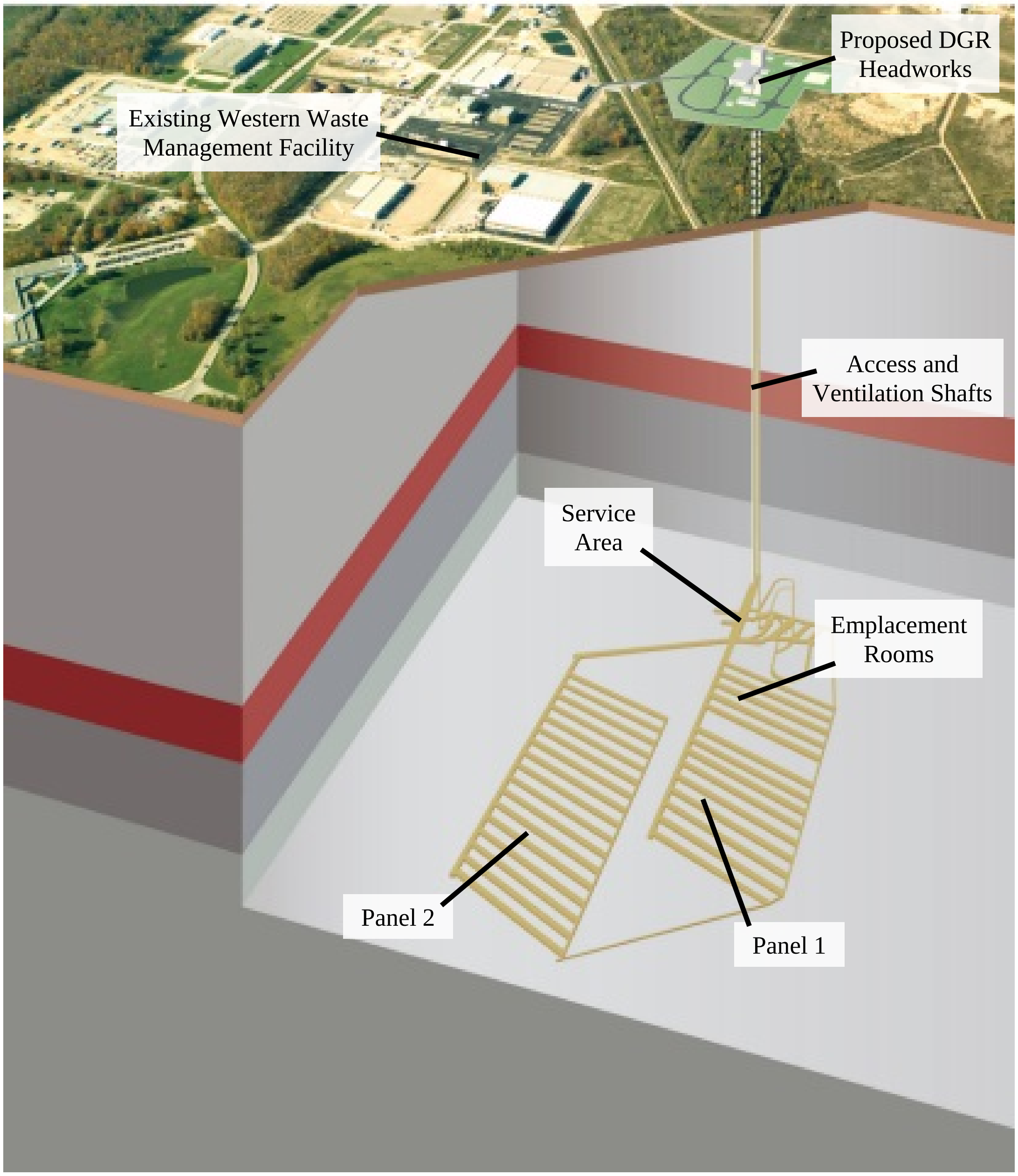

Fig. 3. Schematic of the DGR

POSTCLOSURE SAFETY ASSESSMENT

The approach used to assess the postclosure safety of the proposed DGR draws on international best practice and guidance [5, 6]. The context for the assessment is established and the repository system and its potential evolution described. These descriptions are used to identify calculation cases that merit explicit quantitative consideration. Conceptual and mathematical models are then developed to represent each calculation case, drawing on a consistent understanding of the repository system. Understanding of the repository system is supported by geoscientific understanding and detailed modelling, with:

- gas generation modelling (GGM) coupled with multi-phase flow modelling in TOUGH2 (collectively referred to as T2GGM); and
- groundwater flow modelling with FRAC3DVS-OPG.

The models make use of a comprehensive list of features, events and processes (FEPs) to build confidence that the wide range factors that could potentially affect postclosure safety have been taken into consideration. The FEP list [7] draws on generic lists developed by the Nuclear Energy Agency (NEA) [8] and International Atomic Energy Agency (IAEA) [6].

The assessment models for radionuclide transport and exposure, supporting data and time-dependent outputs from the detailed modelling are then implemented within a 'total system' model implemented in the AMBER compartment modelling software [9]. The software enables models for contaminant release, transport and potential impacts to be implemented in a flexible, transparent, probabilistic and time-dependent framework.

The AMBER model for the DGR includes explicit representation of 21 distinct waste streams, emplacement rooms, access tunnels, damaged zones in the host rock, as well as the closure design, the shafts, the surrounding geological strata, the shallow groundwater system and the biosphere, including a self-sufficient terrestrial exposure group and Lake Huron. The model for the repository is illustrated in Fig. 4. Repository resaturation and gas pressures are drawn directly from T2GGM outputs; these drive radionuclide releases and partitioning of radionuclides between gas and groundwater within the repository.

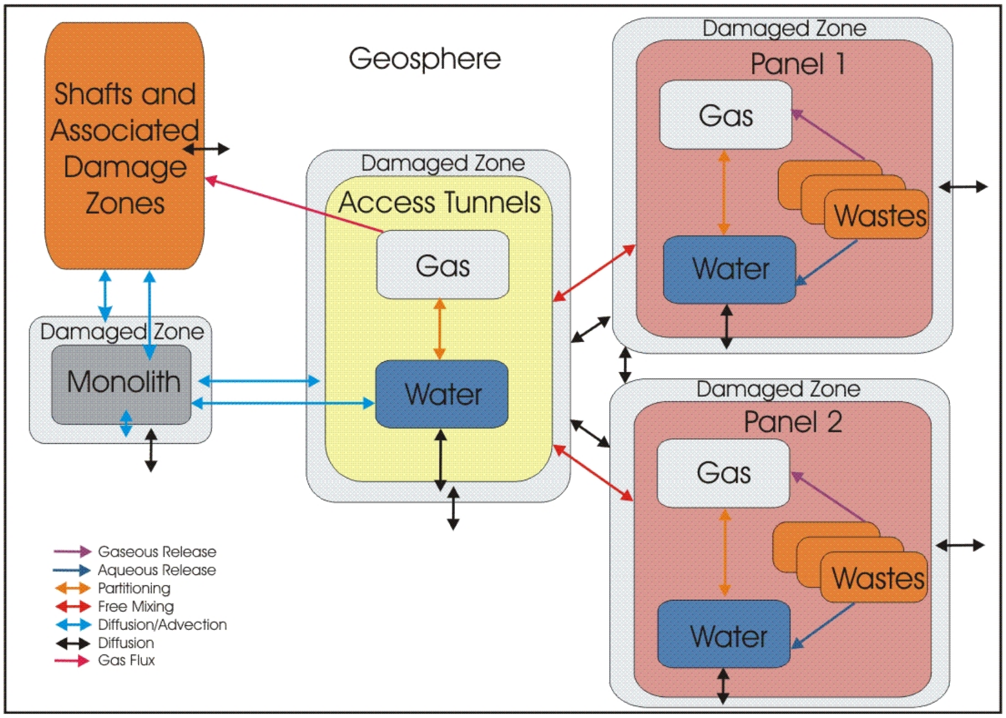

Fig. 4. Schematic of the AMBER Model for the Repository (some of these components are represented with multiple compartments in the model itself)

Once radionuclides are released from the wastes, the model explicitly represents contaminant transport from the DGR via diffusive and advective transport with groundwater and gas flows and diffusion. Gas amounts and gas and groundwater flow rates are drawn directly from T2GGM and FRAC3DVS-OPG outputs. The AMBER model for the access shafts and surrounding geological formations is illustrated in Fig. 5. Radionuclides can be discharged to the surface environment via groundwater discharge to Lake Huron, via a groundwater borehole drilled into the shallow system or, in some conservative 'what if' style calculations, through the discharge of gas via the shafts.

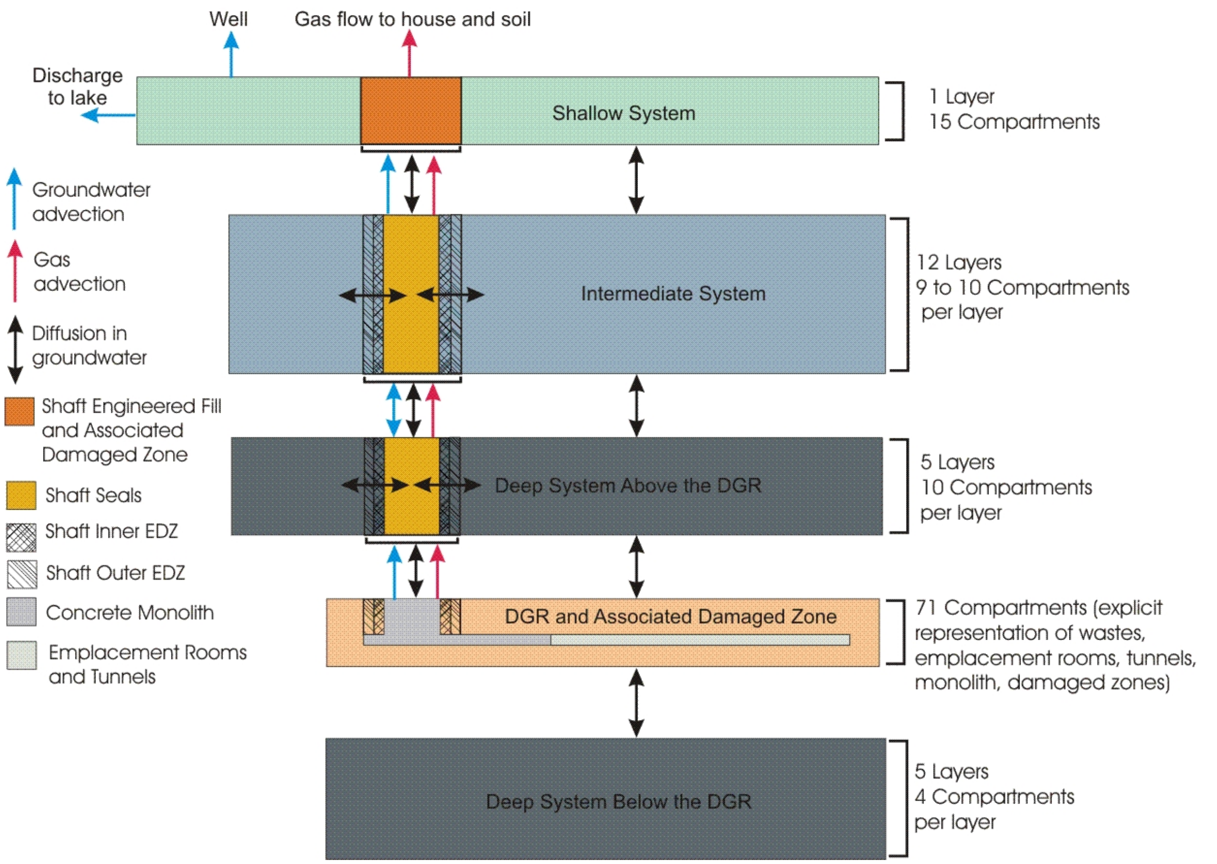

Fig. 5. Schematic of the AMBER Model for the Shafts and Surrounding Geology

The model for the biosphere is illustrated in Fig. 6 and includes terrestrial areas potentially contaminated by use of well water and/or gas from the shafts, a surface water course through a stream and wetland along with a model representing Lake Huron.

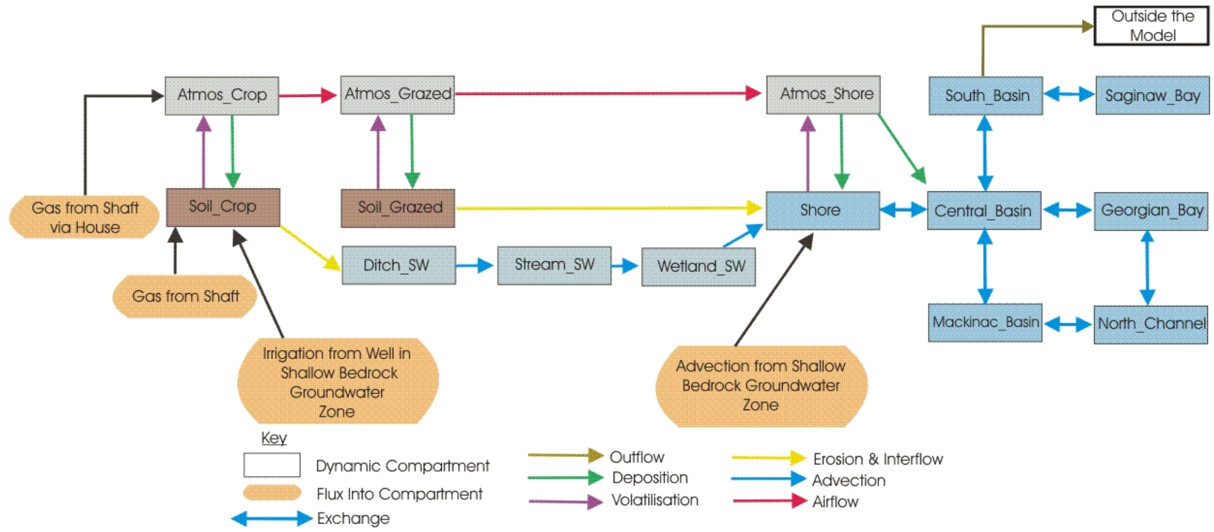

Fig. 6. Schematic of the AMBER Model for the Biosphere

The postclosure safety assessment considers a 'normal evolution scenario', which represents the expected way in which the repository system will evolve into the future [10]. The assessment also addresses alternative worst case situations that involve disruption of the repository system [11]. These 'what if' scenarios include assessment of the potential consequences of human intrusion into the DGR, severe shaft seal failure, a poorly sealed site investigation borehole and a hypothetical transmissive vertical fault in close proximity to the repository.

Conceptual, mathematical and parameter uncertainties are explored within each scenario through a range of deterministic and probabilistic calculation cases. All of the calculation cases assessed are implemented within the same core AMBER models for the nearfield/geosphere and biosphere to facilitate consistency and efficient management of the 31 distinct cases that are assessed. A variant to the AMBER model is used to assess the behaviour of non-radiological contaminants, whereby radionuclides in the model are replaced by heavy metals and organic contaminants.

Some uncertainties are addressed through adopting assumptions that err on the side of overestimating potential impacts, which should be born in mind when interpreting the assessment results. Notable conservative assumptions adopted in the assessment are listed below.

- No credit is taken for the containment offered by waste packaging, nor for that offered by emplacement room seals and other closure walls within the DGR (i.e., the concrete monolith, which is to be emplaced at the base of the shafts on closure, is explicitly represented).
- No credit is taken for sorption of contaminants on concrete, asphalt and engineered fill within the DGR and shafts nor for sorption onto limestone/dolostone in the geosphere (however, sorption is represented for some chemical elements on sand-bentonite within the shafts and on shales).

- The roof of the repository is taken to collapse onto the wastes immediately on closure of the DGR, reducing the thickness of the geosphere barrier, providing a mechanism for waste package failure, minimising the waste stack height, thereby maximising the amount of waste in contact with any repository water.
- The groundwater well is taken to be located at the location where the highest contaminant concentrations would occur in usable shallow groundwater.
- A house is modelled as being located directly above the main shaft and the potential exposure group is taken to maximise its use of local resources through a self-sufficient lifestyle.

RESULTS

The T2GGM modelling demonstrates that the very low hydraulic conductivity of the host rock and the shaft seals, coupled with the gas pressures generated by degrading wastes, results in low levels of repository resaturation under normal evolution conditions. The limited interaction with groundwater means that most of the contaminants remain within the DGR. AMBER results for the central normal evolution cases demonstrate that less than 1% of the initial radioactive inventory is released from the DGR and only 3% of the initial non-radioactive inventory. Most of the contamination that is released from the DGR is lost by diffusion into the host rock; the amount that is released to the shafts and the damaged rock surrounding the shafts is very low (see Fig. 7).

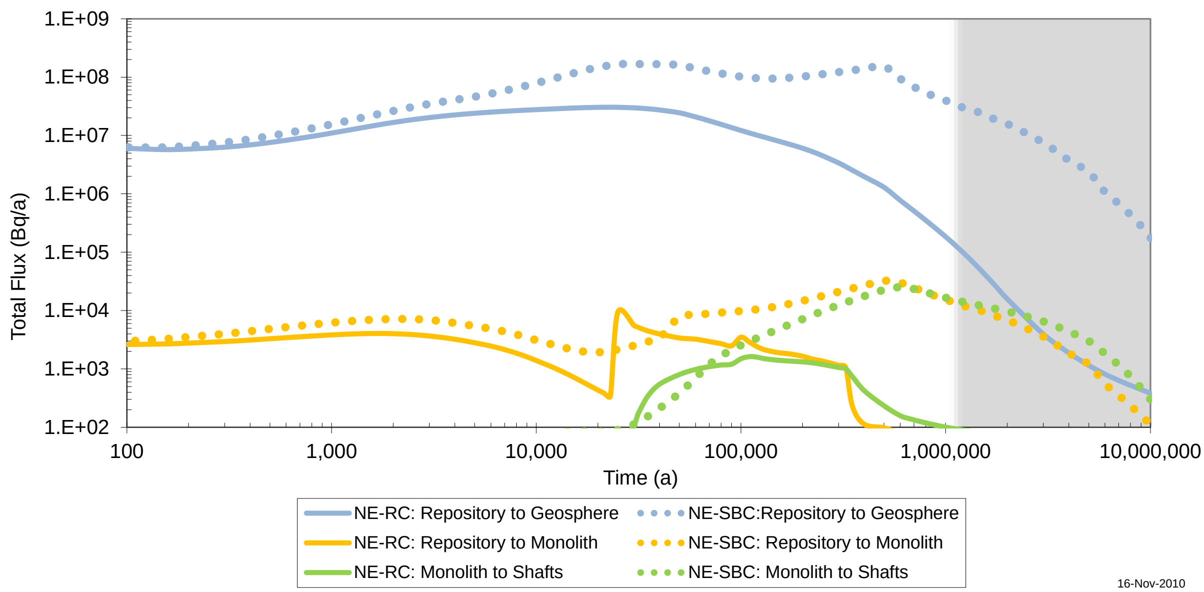

Fig. 7. Total Radionuclide Transfer Fluxes from the DGR for the Central Normal Evolution Scenario Calculation Cases (the NE-RC reference case includes the initial under-pressures in the host rock; NE-SBC simplified base case conservatively ignores the initial under-pressures)

The AMBER modelling shows that the intact host rock provides an effective barrier to contaminant transport. The results show that only trivial amounts of contamination may reach the shallow groundwater system via the shafts and their surrounding damaged rock. Consequently, assessed doses for all normal evolution calculation cases are also trivial and more than five orders of magnitude below the dose criterion of 0.3 mSv/a, even with the conservative modelling assumptions (Fig. 8). Calculated radionuclide concentrations in the biosphere for the normal evolution cases are much smaller than screening 'no effect concentrations' for wildlife. Calculated concentrations of non-radioactive contaminants are also much smaller than environmental quality standards for groundwater, soils, surface water and sediments designed to protect human health and the environment.

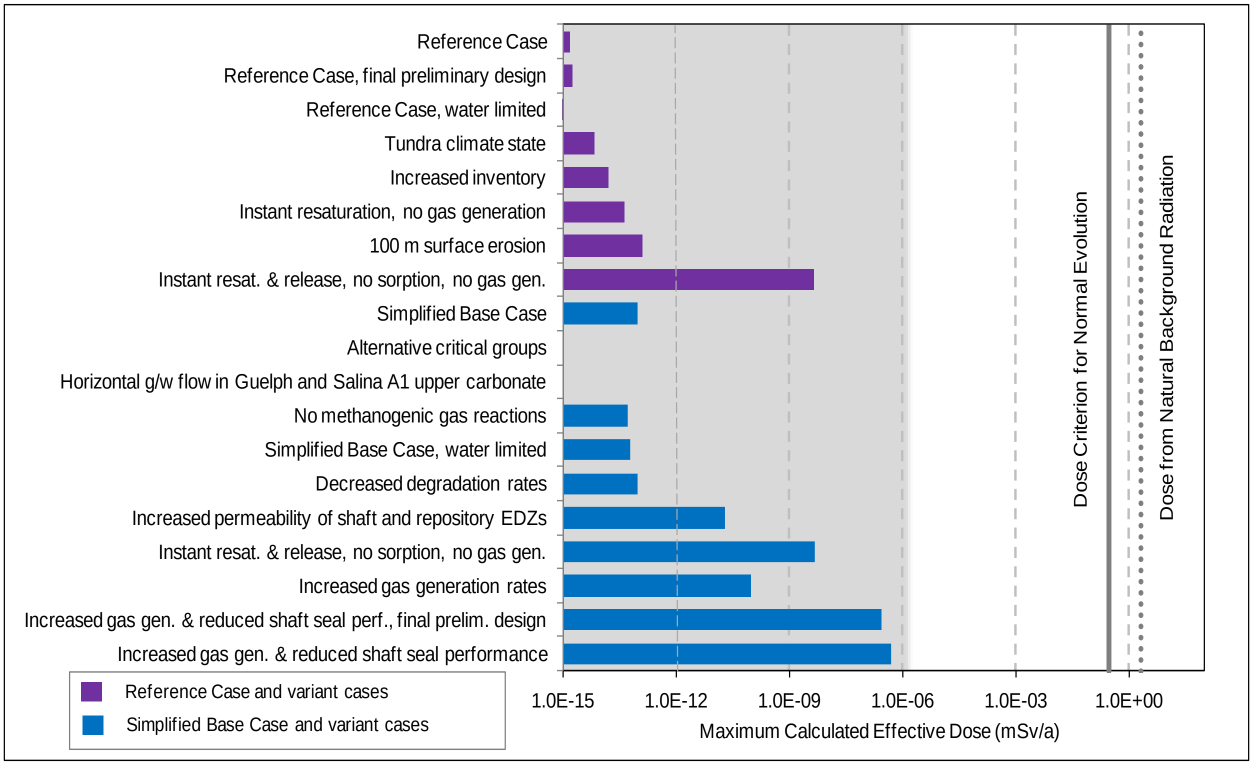

Fig. 8. Maximum Calculated Effective Dose to an Adult for the Normal Evolution Scenario Calculation Cases

For the 'what if' style disruptive cases, calculated doses for the poorly sealed borehole and vertical fault scenarios remain more than five orders of magnitude below the dose criterion of 1 mSv/a (see Fig. 9). Calculated doses for the human intrusion scenario and severe shaft seal failure scenario are close to the 1 mSv/a criterion. These are the maximum doses that would arise if the scenario were to occur. Consideration of the low likelihood of occurrence of these scenarios results in a risk of serious health effects that is significantly less than the reference health risk value for disruptive cases, which is one in 100,000 per year. For the human intrusion case, the highest calculated doses arise due to external irradiation to Nb-94 in the wastes brought to the surface. For the severe shaft seal failure scenario, the calculated dose arise due to C-14 released with gas direct to the surface and to the shallow groundwater due to a gas pathway being forced through after about 20,000 years when the shaft seals are taken to be severely degraded throughout their entire length.

Calculated radionuclide concentrations in the biosphere for the 'what if' style disruptive cases remain below screening 'no effect concentrations' and/or environmental risk assessment criteria for wildlife. Similarly, calculated concentrations of non-radioactive contaminants remain below environmental quality standards.

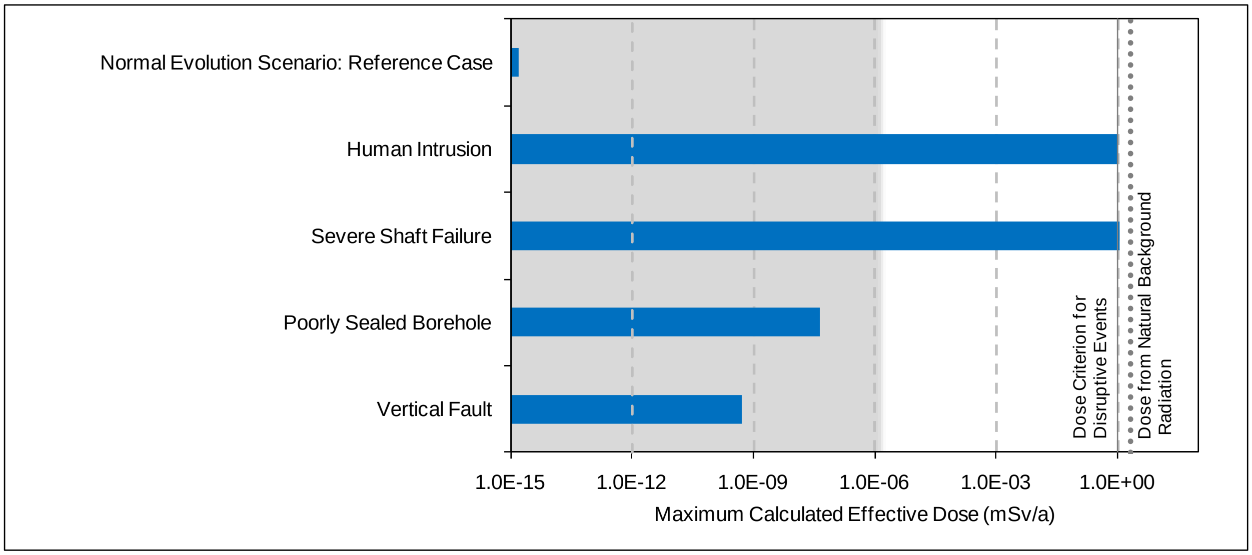

Fig. 9. Maximum Calculated Effective Dose to an Adult for the Central Disruptive Scenario Cases

The assessment models allow the most important safety features for the proposed DGR to be explicitly demonstrated. The results highlight the robustness of the geological barriers at the DGR site and the importance of the multiple shaft seals.

The large safety margin, the direct use of site data, the use of detailed modelling and site interpretation and the comprehensive investigation of uncertainties help to build confidence in the assessment results. Confidence is also drawn from AMBER's status as a fully transparent, robust and widely used assessment code; the quality assurance systems that support the software, the models and their implementation; peer review and audits.

The licence application is subject to review by an independent Joint Review Panel (JRP) that has been appointed by the Canadian Environmental Assessment Agency and the Canadian Nuclear Safety Commission. The JRP is scrutinising the PSR and supporting studies, including the postclosure assessment modelling, as well as holding public hearings. Conclusion of the review process is anticipated in 2015.

CONCLUSIONS

The assessment modelling for the proposed DGR supports the case for safe management of radioactive wastes that remain hazardous on long time scales. In particular, the assessment demonstrates that deep geologic repositories can provide a safe disposal option. The assessment provides an example of evaluating the safety of projects on long time scales within the framework of an internationally accepted approach and for managing the associated uncertainties. It shows how results from detailed groundwater and gas codes can be incorporated into assessment-level codes such as AMBER, thereby providing a single systems model that can be used to evaluate a wide range of scenarios and associated calculation cases.

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